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AD

BROAD TEMPERATURE RANGE OBTURATOR PAD MATERIALS

U.S. ARMY ARMAMENT COMMAND

BENET WEAPONS LABORATORY
WATERVLIET ARSENAL
WATERVLIET, N.Y. 12189

JANUARY 1975

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It is important that obturator pads seal satisfactorily over a wide range of ambient temperatures. This is difficult to achieve at very low temperatures, where the elastomeric pad materials become stiff and fail to transmit pressure hydrostatically as they must for effective obturation. Furthermore, since the coefficient of thermal expansion of an elastomer is about 10 times that of steel, the pad shrinks much more than does its cavity in the breech assembly as the temperature falls. Methods were developed for evaluating these characteristics

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of candidate materials simply and inexpensively. The most promising elastomer was the castable polyurethane made from Adiprene L-42. This elastomer retains excellent flexibility to temperatures below -65°F and pads with very little change in the important diametral direction with temperature can be made by incorporating 1/4 in. glass fibers in the formulation. Adiprene-fiber glass pads have sealed well in both the 175mm Gun M113A1 and the 155mm Howitzer M185 from 125° down to a temperature of -50°F in climatic firing tests at Aberdeen Proving Grounds which corroborates these ideas on the design of obturator pads and the shop methods of evaluation.

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INTRODUCTION

Obturation with cased ammunition, as used in small arms and the smaller cannon, is effected by expansion of the cartridge case by the propellent gas pressure. With bag-loaded ammunition, however, there is no inherent obturation and it must be provided for by the use of a separate seal in the breech mechanism. This obturation, in U.S. cannon, is accomplished by an elastomer pad. The metal anterior portion of the breech block assembly (mushroom head) is forced back by the pressure of the propellant gases thereby producing a force on the obturator pad which is transmitted radially through the seal rings to the tube seat thereby sealing the breech. The two steel seal rings in the breech block assembly at the periphery of the pad protect the elastomer from the hot propellent gases and also insure that it does not extrude through the narrow annular space between the breech block assembly and the tube seat.

It is important that obturator pads function satisfactorily over a wide range of ambient temperatures. The problem is with the very low temperatures. The currently used polyurethane rubber pad functions well to the highest operating temperatures encountered. However, it is only safety certified to a temperature of -10°F in the 175mm Gun M113A1 although a pad of the same material in the 155mm Howitzer M185 is certified to -40°F owing to its smaller size and somewhat different geometry. In any event, low temperatures pose an operational problem because of the poor low-temperature characteristics of the polyurethane

rubber used in the current obturator pads. At present, the pads must be warmed in some way before they can be used at temperatures below those to which they have been safety certified. It would be desirable to extend the lower temperature limits to at least -50°F. The work reported here was done in order to obtain a pad material which will function satisfactorily from 125° to -50°F and so obviate the need for warming the pads for operation at the very low temperatures.

An asbestos-silicone rubber obturator pad utilizing a wire mesh envelope or "basket" has recently been developed for the 175mm Gun M113A1 which is satisfactory down to -50°.[(1)] However, its manufacture is quite complex which makes it expensive and also leads to quality control problems. Furthermore, the use of asbestos in the formulation is another potential problem. Besides the health hazards attendent with handling asbestos, since it is a natural mined product, its character is variable and absorbed impurities can be present which will interfere with the polymerization of the silicone rubber. Because of these disadvantages, despite its good low-temperature capabilities, the asbestos-silicone rubber obturator pad is not entirely satisfactory as a replacement for the current polyurethane rubber pad.

THEORETICAL CONSIDERATIONS

Chamber pressure as a function of time is shown in Fig. 1. The example selected is for a zone 3 round fired in the 175mm Gun M113A1. Firing at other zones and in other cannon result in different propellent pressure characteristics. It is accepted that for effective sealing the sealing pressure must be equal to or greater than the pressure to

[1] Hynes, James T., Silicone-Asbestos Obturator Pads for 175mm Gun, M113A1, A Product Improvement, WVT-7101 (1971)

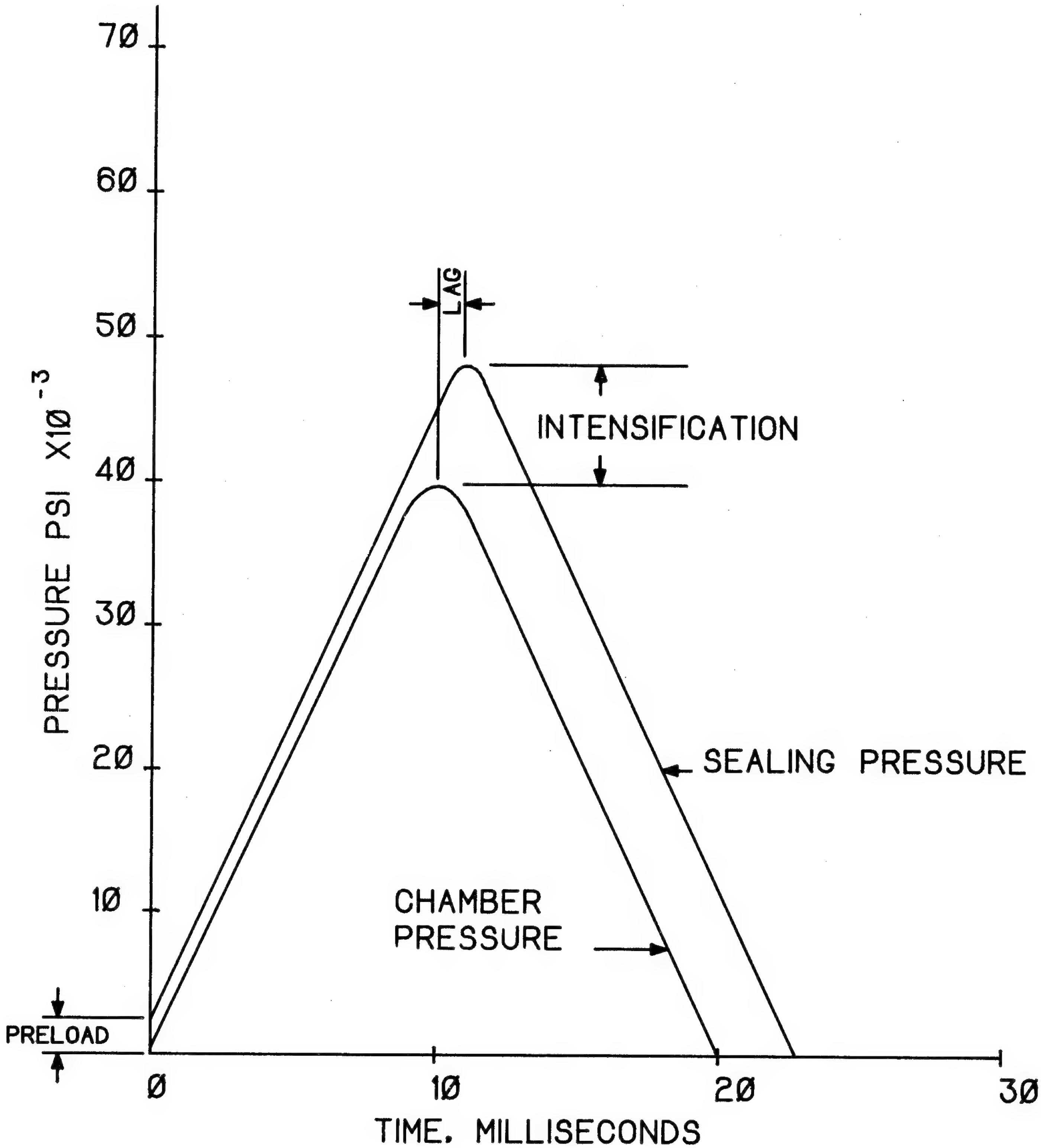

Fig. 1 Diagram showing the pressure response of an obturator pad during firing. The example chosen is a zone 3 round in a 175mm Gun M113A1.

be sealed. (While this doubtless depends upon the specific geometry, etc., variation from this rule will not affect the considerations presented here.) If this is the case, the sealing pressure vs. time curve must be greater than the propellent pressure curve at all times for effective obturation. Obturator pads are designed so that there is an intensification of the propellent pressure owing to the fact that the area of the breech face exceeds that of the supporting area of the obturator pad because of the central spindle hole. Therefore, if the obturator pad behaved as a liquid, the sealing pressure would always exceed the sealed pressure by a comfortable margin.

Basically, there are three different ways that an obturator pad can fail as a seal. (A pad can have insufficient durability, shelf life, oil resistance, etc. but this will not be considered here.)

Flexibility

If the obturator pad material always behaved as a liquid, the pressure transmitted radially would always be equal to the axial pressure on the pad and be greater than the propellent pressure. Unfortunately, while elastomers generally behave hydrostatically at ambient temperature, they stiffen and fail to transmit full hydrostatic pressure radially at lower temperatures. The temperature at which this occurs differs from elastomer to elastomer. The ratio of radial pressure to applied axial pressure is a very useful measure of this important property. This ratio has been termed the "A" ratio in this report after Allen A. Albright Chief of the Product Design Branch at Watervliet Arsenal who first suggested its use.

Speed of response

The A ratio described above is an equilibrium value; however, the pad material property actually of importance is the dynamic value. The pad must transmit the required sealing pressure in a few milliseconds. If the speed of response becomes too slow at low temperatures, the lag in the transmission of sealing pressure will be too great and propellent gas leakage will ensue.

Thermal dimensional stability

The coefficient of thermal expansion of an elastomer is about 10 times that of steel. Therefore, the obturator pad shrinks much more than does its cavity in the breech assembly as the temperature falls. As the pad shrinks, the preload, i.e. the initial sealing pressure, becomes less until the pad fails to seal properly and finally fails to contact the tube seat at all. The important value is the diametral shrinkage. Because of the design of the breech mechanism, rather large axial dimensional changes can be accommodated but this is not true of diametral dimensional changes.

PROPOSED SOLUTIONS TO THE LOW-TEMPERATURE PROBLEMS

A satisfactory obturator pad material for operation at low temperatures must have adequate low-temperature flexibility, speed of response, and dimensional stability. If any of these falls short of the minimum required, the obturator pad will fail to seal. Problems at low temperatures with these properties are more or less intrinsic with the use of a nonmetallic material. However, a suitable elastomer can be designed which will meet all the requirements. The elastomers

selected for the experimental obturator pads were the "castable" polyurethanes. There are a number of reasons for choosing these materials, the most important of which is that they are very versatile and desired properties can be "tailor-made" for a particular application. The characteristics of the castable polyurethane elastomers are discussed more fully in Appendix 1.

Low-temperature flexibility

Elastomers differ greatly in their flexibilities at low temperatures. Essentially, the approach adopted was to select a commercially available elastomer which possessed the required low-temperature properties and also appeared to be a suitable material for obturator pads from the standpoints of cost, durability, oil resistance, and ease of manufacture. An important problem was to establish the minimum values for the A ratio required for satisfactory performance. As discussed in Appendix 2, it was concluded that these values were 0.91-0.92 for the pad for the 175mm gun M113A1 and 0.79 for the pad for the 155mm howitzer M185 from the A ratios at temperatures where pads are known to begin to leak in actual firing. If the A ratios do not fall below these values down to a temperature of -50°F, the pads will give satisfactory performance provided that they are not limited by some other factor. The method of measuring A ratios is also described in Appendix 2.

The A ratios of many different formulations of different prepolymers, different curing agents, admixtures of different plasticizers, etc. were measured. It was concluded that suitable low-temperature properties could not be obtained by the use of plasticizers and that

the prepolymer was, by far, the most influential in determining the A ratio of the elastomer. In the formulations studied, the curing agent affected the A ratio only very little. The prepolymer found to be most suitable and that with which the actual pad development work was done was the duPont product Adiprene L-42. This material is known to produce elastomers with good low-temperature properties and is used where these properties are important. Other manufacturers of ether-type isocyanate prepolymers could no doubt duplicate the characteristics of Adiprene L-42.

Speed of response

While the static A ratio is extremely useful for choosing an elastomer with satisfactory low-temperature properties, the dynamic A ratio is actually the property of importance. This property, however, is difficult to investigate in a realistic way owing to the extremely rapid response required. Therefore, the course adopted was to measure the speed of response at the shortest time feasible with the fastest available instrumentation and then to compare this speed with that of the current pad material, RIA 510 polyurethane rubber, at a temperature where this elastomer is known to be satisfactory. If it is the same or shorter, it is probably likely that it will be the same or shorter in the faster 10 millisecond time frame as well. The comparisons of dynamic A ratios are discussed in Appendix 3.

There were remarkably slight differences among the speeds of response of the different formulations studied. What differences there were were confined to the higher response portions of the curves and

there was only a 6-7% spread between the fastest and the slowest. The Adiprene L-42 formulations were slightly faster than the RIA 510 polyurethane rubber. Temperature too, seems to have little effect on speed of response. All the rubbers were somewhat more sluggish at low temperatures but the differences were not great. The speed of response only decreased 6-7% on cooling from ambient to -65°F. Therefore, it was concluded that while there is an effect of material and temperature on the speed of response of obturator pad materials, it is not large at least for all the materials tested.

Thermal dimensional stability

The thermal dimensional stability of an elastomer can be increased byfilling it with a material which has a small or even negative coefficient of thermal expansion. However, this is limited to a relatively small improvement because the physical properties of the elastomer deteriorate as the amount of filler is increased beyond a certain point. Certainly the required degree of dimensional stability cannot be achieved in this way. Probably the only way to attain the required stability in the radial direction is to make the pad anisotropic, i.e. so that it shrinks more in the axial direction but less radially. This is actually what has been done in the case of the asbestos-silicone rubber obturator pads by the use of the wire mesh basket. Silicone rubber has an even higher coefficient of thermal expansion than do the other elastomers but the pad is constrained in the radial direction by the wire mesh. Therefore, this pad's thermal dimensional stability in this direction is excellent; it does shrink a great deal in the axial direction at the

low temperature but, owing to the design of the breech mechanism, this does not impare its sealing.

Just as with the case of low-temperature flexibility, it is necessary to establish the permissable limits of the diametral dimensions. A pad can then be designed made of an elastomer with suitable low-temperature flexibility which will not exceed these values. This is discussed in Appendix 4. As with the A ratios, these were established by measuring the amount of diametral shrinkage at the lowest temperatures that standard pads seal properly. These values were -0.064 inch for the 175mm gun pad and -0.063 inch for the 155mm howitzer pad. However, there is reason to believe that a value of -0.090 or even -0.100 inch would be satisfactory for the 175mm gun pad from the results of some firing tests a few years ago with an experimental Adiprene L-42 pad.

The least expensive way to design an obturator pad with the required anisotropic characteristics is by incorporating oriented fibers in it. The experimental work for this part of the development is also discussed in Appendix 4. An easy way to attain the orientation is to incorporate reasonably long glass fibers into the formulation and, when the pads are cast in molds, the fibers take up the correct orientation automatically just through the action of gravity. A fiber length of 1/4 inch was found to be adequate. Most of the pads which were field tested were made with Adiprene L-42 cured with the di-β-hydroxyethyl ether of hydroquinone containing 15.0 parts by weight (based on the prepolymer) of 1/4 inch glass fibers. This much glass fiber was used because the

initial information was that a pad with -65°F capabilities was desired. The higher -50°F temperature makes the problem much easier and appreciably less fiber is required.

ACTUAL FIRING EXPERIMENTS

Obturator pads made of some of the experimental formulations were tested in the 175mm gun M113A1 and the 155mm howitzer M185 at temperatures from 125° to -50°F. In addition, there were a number of experimental firings with these pads in the above cannons as well as some in the 155mm howitzer XM199 at ambient temperature. These experiments are described in Appendix 5.

There was a problem with the mold for the pads for the 175mm gun; it produced pads with one of the important peripherial sealing surfaces slightly undersize. In spite of this one of the formulations sealed well from 125° to -50°F even with the 115% upper pressure limit rounds. Another similar formulation sealed well down to this temperature with zone 3 rounds but allowed blow-by with the 115% UPL rounds. This perhaps can be attributed, in part at least, to the original undersize dimensions of the experimental pad. The high-temperature firing experiments indicated that a harder, tougher formulation would give greater durability but there was little damage to the pads even after quite a number of rounds at ambient temperature.

The mold for the pads for the 155mm howitzer produced pads with good dimensions. Furthermore, this cannon is considerably easier to seal. The formulation which had failed at -50°F with the 115% UPL

rounds in the 175mm gun performed well at this temperature in the 155mm howitzer M185; it was completely satisfactory from a temperature of 125° to -50°F. This particular formulation, however, was not satisfactory in the ambient temperature testing with the 155mm howitzer XM199. The pads did not leak but, owing to the high chamber pressure and the breech design, fragments of the pad lodged at the split in the front seal ring which made the breech difficult to close after a few rounds.

CONCLUSION

The problem in designing broad temperature range obturator pads is with the operation at very low temperatures. At these temperatures the elastomeric pad materials become stiff and fail to transmit pressure hydrostatically as they must for effective sealing of the breech. Furthermore, since the coefficient of thermal expansion of an elastomer is about 10 times that of steel, the obturator pad shrinks much more than does its cavity in the breech assembly as the temperature falls. As the pad shrinks, the initial sealing pressure becomes less until the pad fails to seal properly and finally fails to contact the tube seat at all.

Methods were developed for evaluating these characteristics of candidate obturator pad materials simply and inexpensively in the shop. The most promising elastomer was the castable polyurethane made from Adiprene L-42. This elastomer retains excellent flexibility to temperatures below -65°F. Anisotropic pads could also be made from this elastomer by incorporating 1/4 inch glass fibers in the formulation.

In this way the pad was constrained from changing dimensions in the important diametral direction.

These ideas on the design of obturator pads and the methods of evaluation were corroborated by the climatic firing experiments. An Adiprene-fiber glass formulation used in a pad for the 175mm gun M113A1 obturated well between 125° and -50°F even with 115% upper pressure limit rounds. An Adiprene-fiber glass formulation also performed well over this same temperature range in the 155mm howitzer M185. The sealing problems in the 155mm size, however, are not severe and can be met by some conventional rubber formulations. Therefore, a new Adiprene-fiber glass obturator pad for this cannon is probably not warranted unless a -65°F capability is desired. This is not true for the larger cannon where a sophisticated composite pad is probably the only answer to the demanding requirements.

RECOMMENDATIONS

Further development of this obturator pad material would be desirable. The formulation used in the firing experiments was designed for operation down to -65°F. If operation to only -50°F is required, less fiber should be used in the formulation. This would make the formulation easier to handle during manufacture. Furthermore, since the glass fiber lowers the flexibility of the elastomer somewhat, a smaller fraction in the formulation would allow the use of a greater variety of curing agents without low-temperature flexibility problems. This would be helpful because an elastomer with more hardness and durability would be desirable especially for rapid fire at elevated temperatures.

REFERENCES

[1] Hynes, James T., Silicone-Asbestos Obturator Pads for 175mm Gun, M113A1, A Product Improvement, WVT-7101 (1971)

ACKNOWLEDGMENT

The aid of Allen A. Albright, Chief of the Design Branch, Watervliet Arsenal, in understanding the cannon problems should be acknowledged. In addition, a great many men of the Development Engineering and Quality Assurance Directorates at Watervliet as well as Robert Ofner of the Nonmetallic Materials Branch of the Gen. Rodman Laboratory at Rock Island and Elliot Brown of the Special Products Division at Garlock, Inc. were of very great assistance in this development.

APPENDIX 1

Castable Polyurethane Elastomers

The elastomers selected for the experimental obturator pads were the "castable" polyurethanes. Excellent mechanical properties can be obtained with these materials and the solvent resistance is good (similar to that of the current polyurethane rubber pads). The fabrication method is inexpensive with good quality control. Any desired materials such as fibers, plasticizers, etc. can easily be incorporated into the formulation so that elastomers with desired properties can be "tailor-made" to a requirement. Furthermore, pads could be made without the extensive rubber handling equipment required for the conventional molded obturator pads. This could be of value in case of mobilization.

The castable polyurethane system is comprised of a prepolymer, a curing agent, and components such as plasticizers and glass fibers which are added to impart special characteristics to the elastomer. The prepolymer is a relatively short-chain linear polymer which is terminated by isocyanate groups and is a liquid with the consistancy of honey. The curing agent is a simple molecule with two or more active hydrogen atoms which react with the isocyanate groups of the prepolymer to produce a long chain polyurethane structure. After the curing agent and any other desired materials are added to the prepolymer, dissolved air is removed from the mixture and it is poured into a mold. The mold is then heated to perhaps 212°F and pressure is usually applied to insure the absence of air bubbles in the finished product. After a

short time, the mold is opened and the piece removed to be cured to completion by heating for a time in an oven.

Any chemical with two or more active hydrogen atoms can serve as a curing agent for the isocyanate prepolymers. The common curing agents are diamines and polyol compounds; MOCA*, a compound manufactured by duPont as well as others, has been the standard diamine curing agent for many years and HQDBHEE**, used in many of the formulations in this study, is an example of a dihydroxyl or diol curing agent. The diamines have been popular because they produce rather hard, very durable polyurethanes with excellent mechanical properties and are very convenient to use. The polyol curing agents, on the other hand, generally produce softer elastomers when used with the same prepolymers. Furthermore, they often have much longer cure times although the cure can be accelerated with catalysts. The toxicity of diamines is a serious disadvantage to their use. By government regulations, the most used representative, MOCA, must now be handled with a great deal more care and precautions than was the case heretofore. MOCA, however, continues to be used because of its many desirable properties although the new handling regulations make its use more expensive. (It should be pointed out that the toxicity problem is confined to the curing agent itself. Elastomers made with MOCA are no more toxic than any others.) The polyol curing agents do not have the toxicity problems of the diamines. With a diol cure, compounds having more than two

* 4,4' Methylene-bis-(2-chloroaniline)
** Di-β-hydroxyethyl ether of hydroquinone

hydroxyl groups are sometimes added to the formulation to produce additional crosslinking which is sometimes desirable. In this study such a crosslinking agent, TMP*, was used in some of the HQDβHEE cured formulations.

Prepolymers are of two basic types; the backbone can either be comprised of polyester links or it can be comprised of ether links. The Witco product, Formrez, is an example of the former and the duPont product, Adiprene, an example of the latter. The polyether structure is probably more suitable for an obturator pad because it is more resistant to hydrolysis and so is more resistant to the action of moisture although, on the other hand, it is slightly less resistant to oil and solvents. The mechanical properties of a castable polyurethane rubber are controlled for the most part by the character of the prepolymer; this component makes up, by far, the largest fraction of the formulation. A study in connection with the work reported here indicated that good low-temperature flexibility, the mechanical property of most importance in this study, was almost entirely controlled by the pre-polymer; this component makes up, by far, the largest fraction of the formulation. In addition to the two basic types of prepolymers, there are numerous different grades of each which differ in the structures of their individual repeating units, their molecular weights (degree of polymerization),

*Trimethylol propane

proportion of isocyanate groups, etc. The ether-type prepolymer, Adiprene L-42, is used where the rubber must have excellent low-temperature properties and was found to be the most suitable prepolymer for broad temperature range obturator pads of all those investigated.

APPENDIX 2

Comparison of A Ratios

The ratio of the applied axial pressure to the pressure transmitted in a radial direction is termed the "A ratio" in this study. This ratio is of extreme importance for an obturator pad material because the chamber pressure must be transmitted relatively undiminished to the tube seat for an effective seal. A material which acts like a liquid, which includes most elastomers at ambient and high temperatures, has an A ratio of 1.00. Elastomers, however, commonly become harder, less flexible, and their A ratios become appreciably lower than this value at low temperatures. The temperature at which this occurs varies with different elastomers. The measurement of A ratios at low temperatures was used to choose a pad material which would have satisfactory properties at these temperatures.

The A ratio for a candidate elastomer was measured by applying an axial force on a specimen and measuring the radial pressure developed. The force was applied with an hydraulic press and its magnitude measured with a conventional load-cell system. The elastomer specimen was a cylindrical slug of material 23/64 to 3/8 in. in diameter and 5/8 in. long. It was confined in a test device which consisted of a steel cylinder with a 3/8 in. diameter axial hole and side walls 0.185 in. thick. It was 1 3/4 in. long with 1/2 in. of each end castellated to avoid end effects but provide guides for the movable pistons which bear on each end of the specimen. The radial pressure developed on the side walls was measured with two strain gages oriented in the

circumferential direction at the midpoint of the cylinder. The outputs of the gages were almost always essentially the same and were averaged for the reported value. Measurements at low temperatures were made by maintaining the entire assembly at the test temperature by means of a dry ice-alcohol freezing mixture. A dummy strain gage mounted on an identical steel block in the freezing mixture provided temperature compensation.

The test device was initially calibrated by filling it with hydraulic oil and using "O" ring seals on the ends of the movable pistons. This method, however, suffered from the fact that it was extremely difficult to control precisely the height of the column of oil in the test device. After it had been determined that Adiprene L-42 cured with MOCA had an A ratio of 0.99 - 1.00 even down to a temperature of -65°F, the device was calibrated with a standard slug of this material which had precisely the correct dimensions.

The determination was made by applying loads of 3,000, 4,000, 5,000, and 6,000 lbs with the hydraulic press to the test device after it had been allowed to stand a sufficient time in the freezing mixture to attain the test temperature. The A ratios at these loads were computed and the value at 5570 lbs (50,000 psi) obtained by interpolation. For most elastomers, the A ratio decreases slightly with increasing pressure. The reproducibility of the measurement appeared to be $\pm$ 0.01 for homogeneous materials. In the case of heterogeneous materials, such as those containing glass or asbestos fibers, the reproducibility was not this good. In any case, at least two measurements were averaged for

the reported value. When these two measurements did not agree, more determinations were made.

The A ratios as functions of temperature for elastomers used in pads for the 175mm gun M113A1 where there is low-temperature firing experience are shown in Fig. 2. The RIA 510 polyurethane rubber is the material of the currently used obturator pads; these pads are safety certified in this cannon to a temperature of -10°F. The A ratio at this temperature is about 0.92. Pads of this same material are safety certified to a temperature of -40°F in the 155mm howitzer M185; its A ratio at this temperature is only about 0.79. The asbestos-silicone rubber pad material has much better low-temperature properties. Pads of this material will seal satisfactorily to -50°F in both cannons; its A ratio at this temperature is about 0.91. There were also two pads of Adiprene L-42 cured with MOCA tested at low temperatures in the 175mm gun M113A1 a few years ago.[1] They were found to obturate completely satisfactorily only to a temperature of -10°F although the A ratio of this material is 1.00 all the way down to a temperature of -65°F. Evidently, their low-temperature performance was limited by a characteristic other than flexibility (presumably dimensional shrinkage) and this information is useless for establishing the lower permissible limit of the A ratio.

From the above facts it was concluded that an A ratio of 0.91-0.92 will result in satisfactory performance with the 175mm gun provided the pad is not limited by some other factor. (The converse, on the other hand, is not necessarily true - that an elastomer with an A ratio somewhat

[1]Hynes, James T., Silicone-Asbestos Obturator Pads for 175mm Gun, M113A1, A Product Improvement, WVT-7101 (1971)

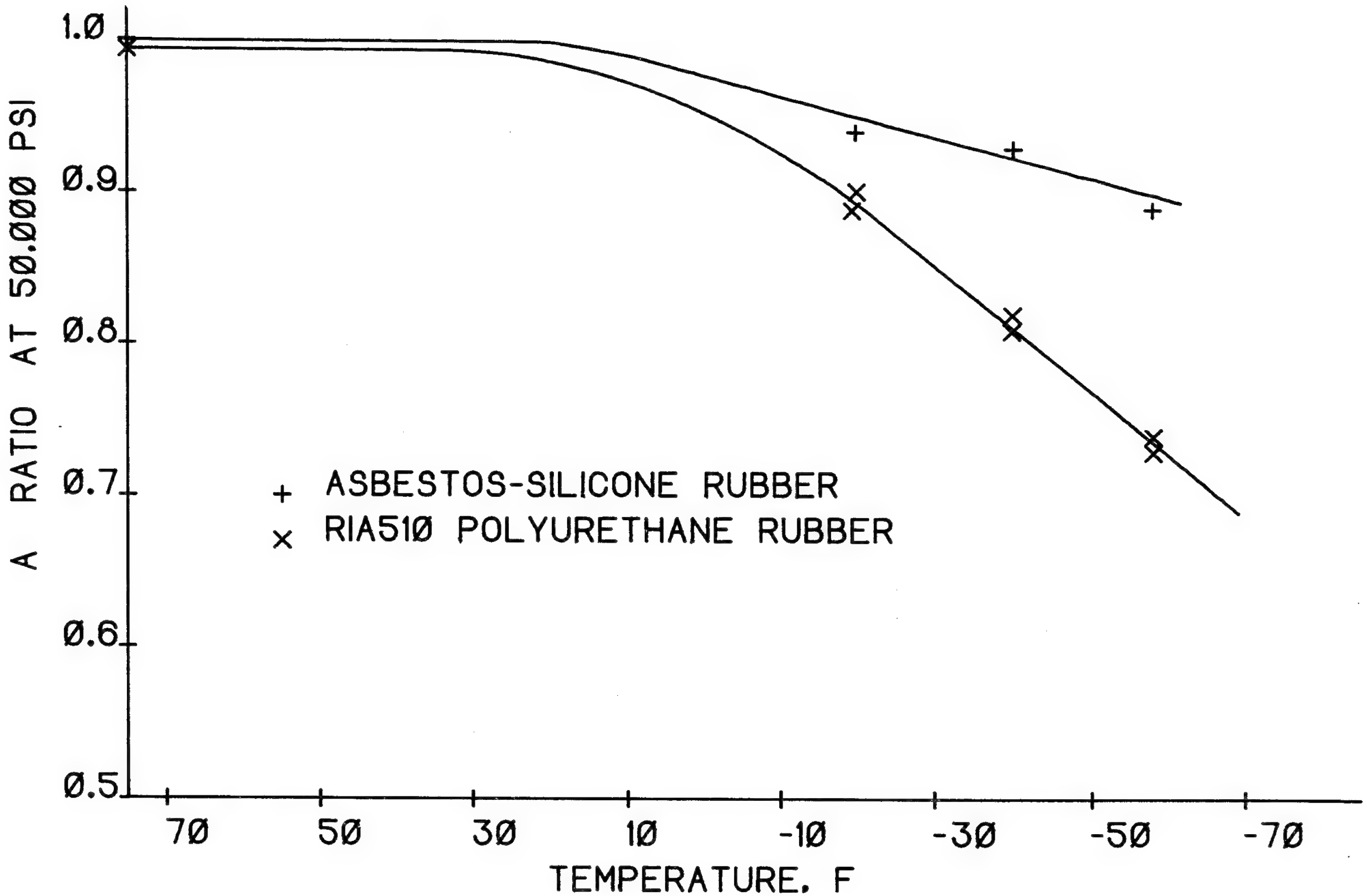

Fig. 2 A ratios as functions of temperature for elastomers used in obturator pads for the 175mm Gun M113A1 where there is low-temperature firing experience. The RIA 510 polyurethane rubber is the material of the currently used pads.

below this value will fail to obturate properly.) Therefore, an elastomer whose A ratio remains above 0.91-0.92 down to -50°F will have satisfactory low-temperature flexibility for a broad temperature range obturator pad for the 175mm gun. The minimum permissible A ratio for satisfactory obturator pad performance in the case of the 155mm howitzer M185 is much lower than that for the larger cannon. This is no doubt because the pressure intensification of this breech mechanism is substantially greater than it is with that of the 175mm gun owing to the fact that the spindle hole in the pad is proportionally much larger. In any event, the value of 0.79 can be chosen as the lower permissible limit for the A ratio for the material of the pad for the 155mm howitzer.

The A ratio as a function of temperature for two other pad materials is shown in Fig. 3. The oil-asbestos composition used in the obturator pad for the 8 in. howitzer is not an elastomer. A satisfactory pad material does not have to be an elastomer; it must just act like a liquid at high pressures and transmit the required radial sealing pressure. The oil-asbestos composition has better low-temperature properties than does the RIA 510 polyurethane rubber; the A ratio does not fall to 0.92 until it reaches a temperature of -25°F. The A ratio data for a sample of the Neoprene used in the obturator pads manufactured by Garlock, Inc. for the 165mm demolition gun are also plotted in this figure. This Neoprene is remarkable in that its A ratio never reaches a value higher than 0.82 even at ambient temperature. This was the only pad material tested which did not have a value of about 1.00 at ordinary temperatures. Perhaps this low A ratio contributes to the low-pressure leakage which, according

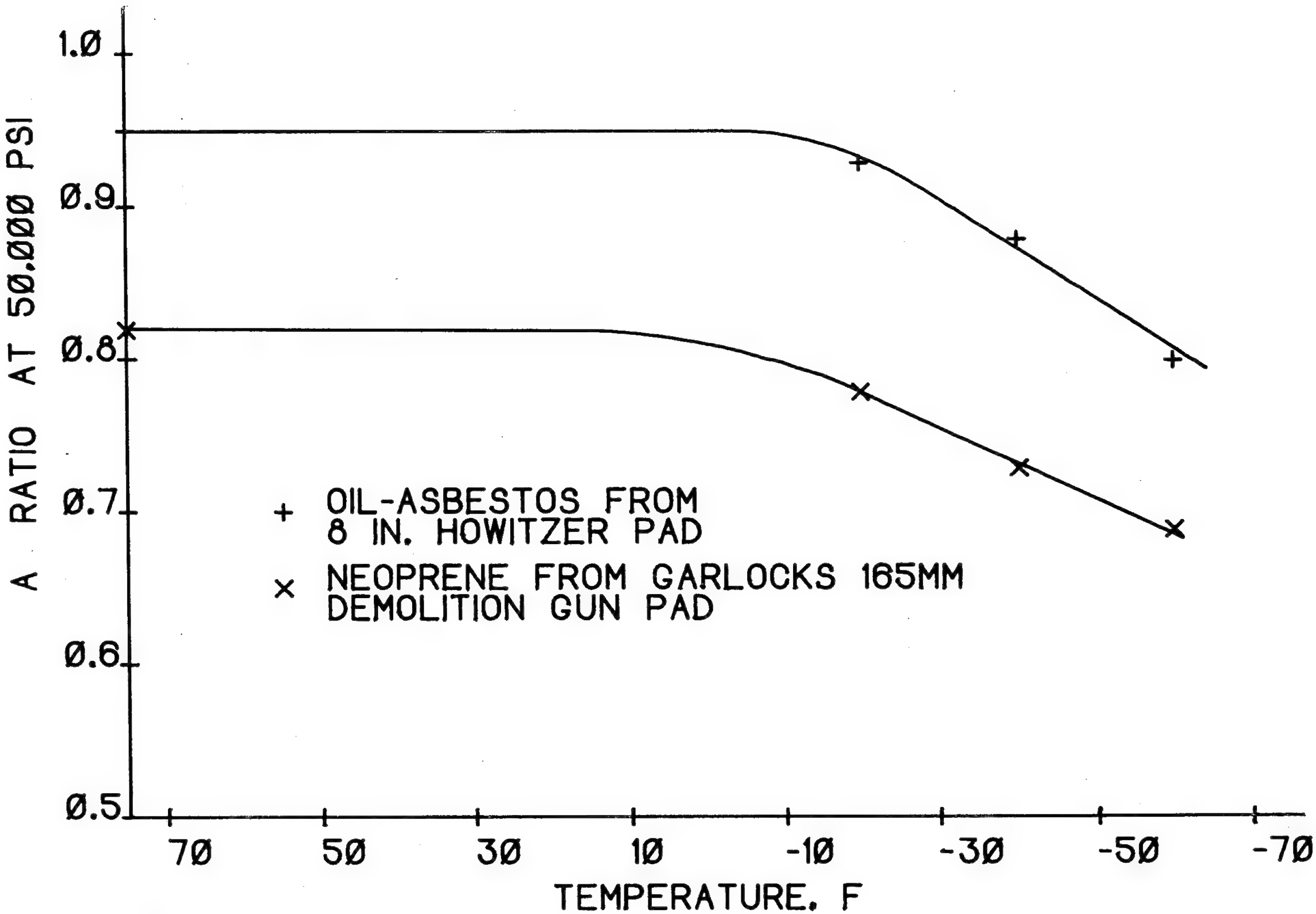

Fig. 3 A ratios as functions of temperature for other obturator pad materials.

to some authorities, is a characteristic of this gun.

The A ratios for various experimental compositions as functions of temperature are shown in Fig. 4. The formulations are given in Tables I and II. The Formrez 319 formulation has even poorer low-temperature properties than does the currently used RIA 510 polyurethane rubber and so clearly its use cannot be considered. The A ratio for the Hydrin 200 formulation, a molded and not a cast elastomer, was 0.90-0.91 at -50°F and so, if the other properties were all right, could probably be used satisfactorily in the pad for the 175mm gun down to this temperature. (The A ratio for the Hydrin 200 formulation obtained from the Nonmetallic Materials Branch of the Gen. Rodman Laboratory at Rock Island Arsenal was considerably lower than this but it was an entirely different formulation.) The A ratio of the Nordel 1070 composition obtained from the Rodman Laboratory also had approximately this same value at -50°F and so could also probably be used satisfactorily down to this temperature if the other properties were all right. The Neoprene WD composition obtained from the Rodman Laboratory had an A ratio of 0.92 at -50°F and so would be expected to be satisfactory at this temperature at least as far as its ability to function hydrodynamically is concerned. However, for low-temperature operation in the 175mm gun at least, a great deal more thermal dimensional stability is required than possessed by any of these elastomers. The addition of glass fibers or, for that matter, any inert material to obtain thermal dimensional stability lowers the A ratio so it is mandatory to start with a composition with a ratio well over 0.92 at -50°F. All of the Adiprene

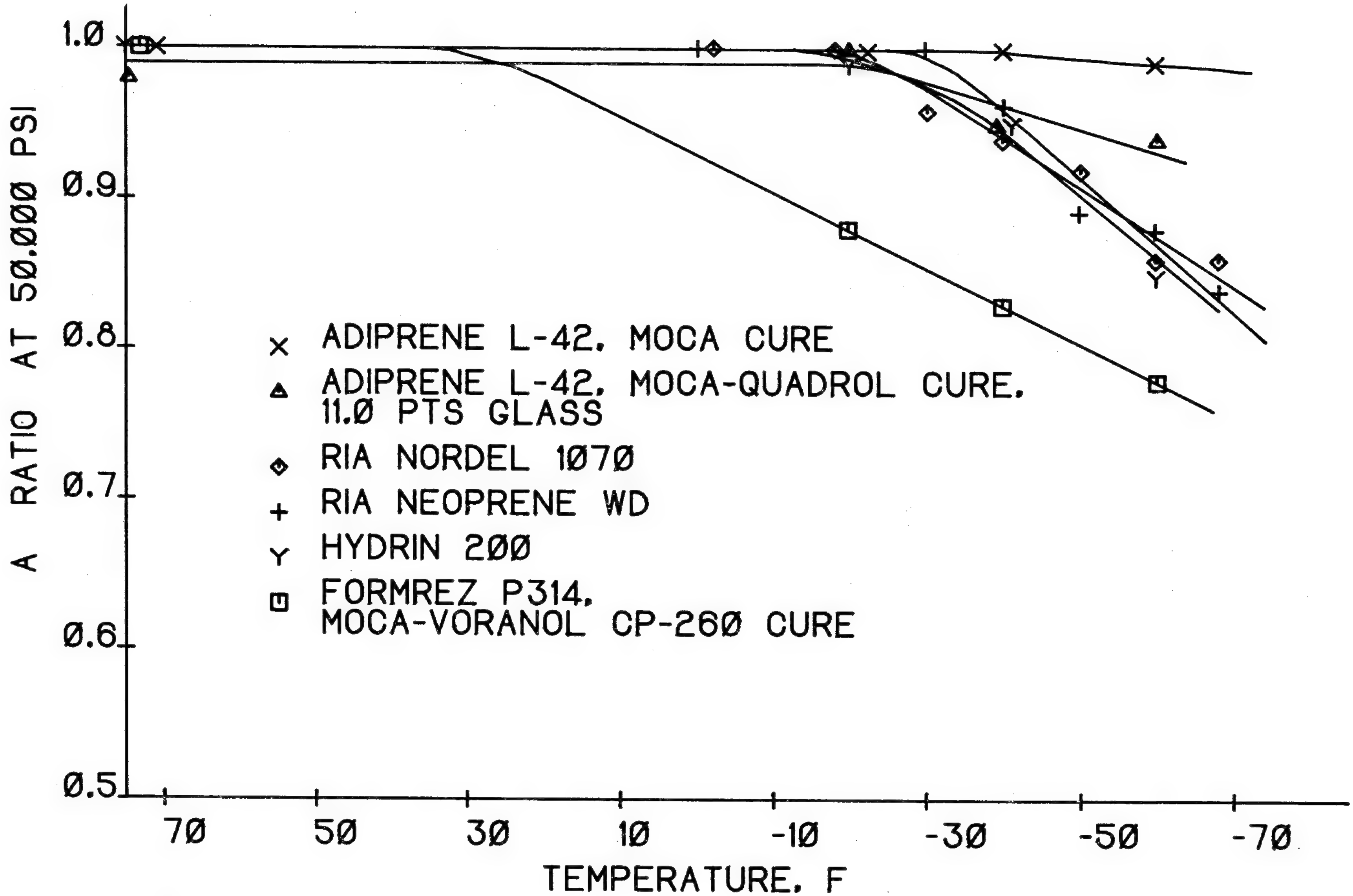

Fig. 4 A ratios for various experimental compositions as functions of temperature. The formulations are given in Tables I and II.

TABLE I

COMPOUND FORMULATIONS FOR OBTURATOR PAD "A" RATIO TEST

SAMPLE NUMBER Compound Ingredients	Parts by Weight 1	2	3	4	5	6	7	8
Adiprene L-42	100	100	100	100	100	100		
Formrez P314							100	
Hydrin 200								100
MOCA	8.8	7.0					4.5	
HQDBHEE			6.0	5.7	5.7	5.7		
TMP				0.29	0.29	0.29		
Voranol CP-260							2.9	
Quadrol		1.0						
N 990 black								100
N 326 black								25
TP-90B								21
Zn stearate								1
Dyphos								5
NBC								0.5
ZO-9								1.5
NA-22								1.25
glass fibers (1/4 in.)		11.0			12.6	14.9		
"A" ratio at -65°F	0.99	0.94*	0.99	0.98	0.97	0.98	0.78*	0.85*

* "A" ratio determined at -60°F

TABLE II

COMPOUND FORMULATIONS FOR OBTURATOR PAD "A" RATIO TEST

OBTAINED FROM THE RODMAN LABORATORY

SAMPLE NUMBER	1	2	3	4	5	6	7
			Parts by Weight				
Compounding Ingredients	M118-3	Z140A1	U88-2	U88	Z197	U80-88	U89
Neoprene WD	100						
Nordel 1070		100					
Formrez MG-2			100				
Vibathane 5004				100			
Hydrin 200					100		
Adiprene L42						100	
Genthane S							100
Akroflex CD	3						
Maglite D	4						
Statex 125	55						
Plasticizer DOS	35						
Zinc Oxide	5						
NA-22	1				1.5		
Philblack N110		50					
Di Cup R		3.5					
Tetrone A		1					
Philblack N550			25	25	40		38
Di Cup 40C			3	4			
Stearic Acid			0.25	0.2			0.2
Stabaxol PCD			4	4			4
Red Lead					5		
Age Rite Resin D					1		
Lithium Stearate					1		
MOCA						8.8	
"A" ratio at -65°F	0.85	0.86	0.58	0.71	0.77	1.00	0.70

L-42 formulations tested (both MOCA and hydroxyl cures) had A ratios of 0.99-1.00 down to a temperature of at least -65°F. Even when large proportions of glass fiber were added to the formulation, the A ratios were well over 0.92 at -65°F.

For the remainder of the study, since the A ratios of the Adiprene L-42 compositions were so high, only the values at -65°F were measured. The samples obtained from the Rodman Laboratory (with the exception of the Neoprene and the Nordel compositions discussed above) were also only investigated at this temperature. The values for the Rodman formulations are given in Table II.

APPENDIX 3

Comparisons of Dynamic A Ratios

While the static A ratio is extremely useful for choosing an elastomer with satisfactory low-temperature properties, the dynamic A ratio is actually the property of importance. An obturator pad must develop the required sealing pressure within a few milliseconds. The dynamic A ratio is extremely difficult to investigate in a meaningful way. A pressure of over 40,000 psi must be applied axially to the elastomer in 10 milliseconds and the radial pressure measured in this same time frame. While a method for loading the specimen this rapidly could be devised, the speed and accuracy required of the radial pressure measurement exceeds that of any instrumentation ordinarily available. Because of these considerations the course adopted was to measure the speed of response at the shortest time feasible with the fastest available instrumentation and then compare this speed with that of RIA 510 at a temperature where this elastomer is known to be satisfactory. If it is the same or shorter, it is likely that it will be the same or shorter in the 10 millisecond time frame too.

These measurements were made using an Instron tester in the compression mode. The same test fixture was used as in the static A ratio measurements except that, in this case, the output of only one of the two circumferential strain gages was measured. It was recorded at a chart speed of 10 inches per second. A maximum compressive force of approximately 6000 pounds (54,000 psi) was used for all the experiments but there was some variation from experiment

to experiment because the ram travel was controlled rather than the compressive force. The load was adjusted to 6000 pounds statically before the dynamic experiment. The electronic control used for vibration testing was used to apply the load. The single activating pulse used was in the form of a square wave so the speed of loading was only limited by the speed of response of the hydraulics. Ordinarily, the ram was a short distance above the test device so that the compressive pulse was actually in the form of a blow. The low-temperature experiments were carried out by cooling the test device in a dry ice-alcohol freezing mixture in a RTV vessel molded onto the lower ram of the Instron.

In these experiments, only the speed of response was of concern. The magnitude of response varied with test rubber and temperature but this was better studied under static conditions. The time required for the strain gage response to reach the different fractions of the maximum strain was determined. There were differences in the initial portions of the curves because the specimens did not fill the test cavity to precisely the same extent. Therefore, all the data were "normalized" by equating the times for a 10% relative response.

As can be seen from Fig. 5, there were remarkably small differences among the different rubbers tested. What differences there were, were confined to the higher response portions of the curves and there appears to be only a 6-7% spread with Adiprene L-42 (MOCA cure) without glass fiber responding fastest and RIA 510 polyurethane rubber responding slowest. Temperature too, seems to have remarkably little effect on speed of response. All the rubbers were somewhat more sluggish at

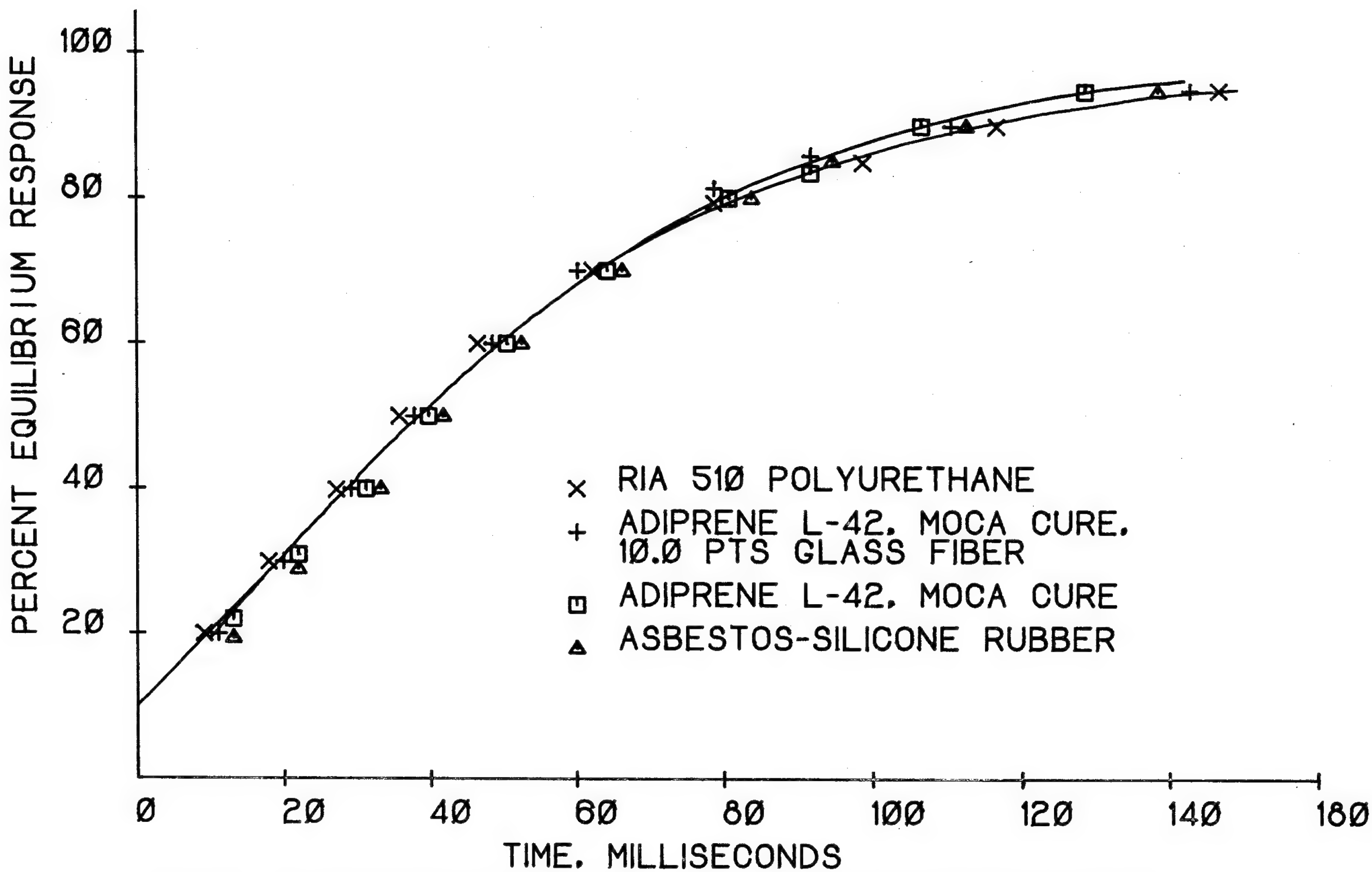

Fig. 5 Dynamic A ratio responses for various elastomers at ambient temperature.

low temperatures but the differences were not great. The data for RIA 510 polyurethane shown in Fig. 6 are typical. The speed of response only decreases 6-7% on cooling from ambient to -65°F. Therefore, it was concluded that while there is an effect of material and temperature on the speed of response of obturator pad materials, it is not large at least for all the materials tested. Of course in the case of material for pads for a critical application such as the 175mm gun, differences of a few percent in the speed of response could be important. However, with differences this small, the measurements were not sufficiently reliable to choose from among the candidate elastomers.

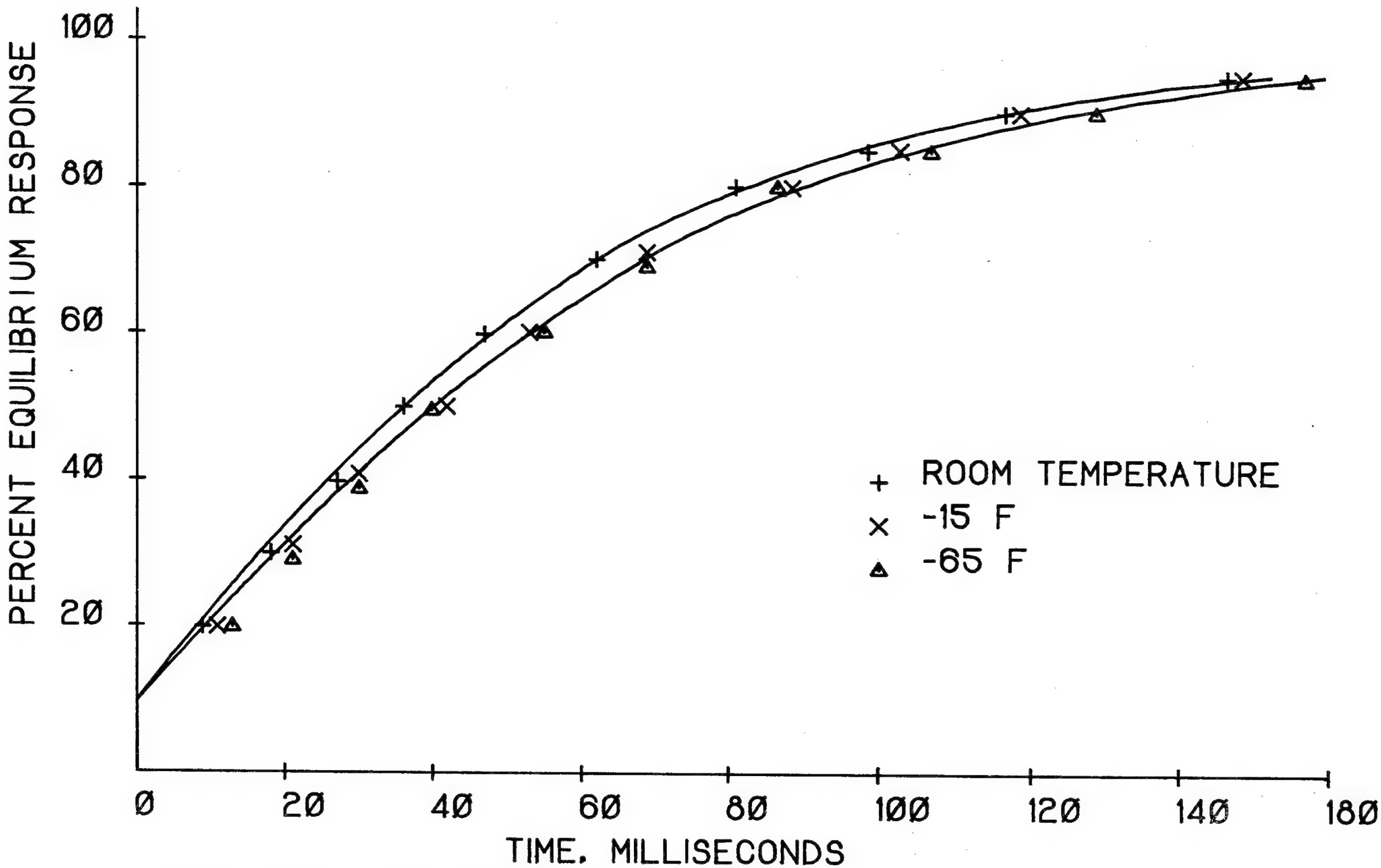

Fig. 6 Dynamic A ratio responses for RIA 510 polyurethane rubber at three temperatures.

APPENDIX 4

Thermal Dimensional Stability

The thermal dimensional stability of obturator pads of different materials was determined by comparing the outside diameters of the pads at different temperatures with the value at ambient temperature. Ordinarily, measurements were made only at the low temperatures; it was felt that since the temperature span between 78° and 125°F was so small, the lower temperature data could reliably be extrapolated to this higher temperature. From the high-temperature measurements which were made, it appeared that this is indeed the case. An actual obturator pad rather than merely a piece of the pad material was used for the measurements because several of the compositions of interest were strongly anisotropic. Even pads of the same composition but with slightly different sizes and shapes had significantly different thermal stabilities. The initial study was done with obturator pads the configuration of those for the 165mm demolition gun because there was a suitable mold available for this pad. Later, when pads for the 175mm gun were available, these were used. Although the pads for the 165mm demolition gun and the 175mm gun are somewhat similar in size and shape, this change led to substantially different values of dimensional stability.

The diametral changes as functions of temperature for the 175mm gun pads for which there is firing experience are shown in Fig. 7. These are the currently used RIA 510 polyurethane rubber pads, the asbestos-silicone rubber pads, and two experimental MOCA cured Adiprene L-42

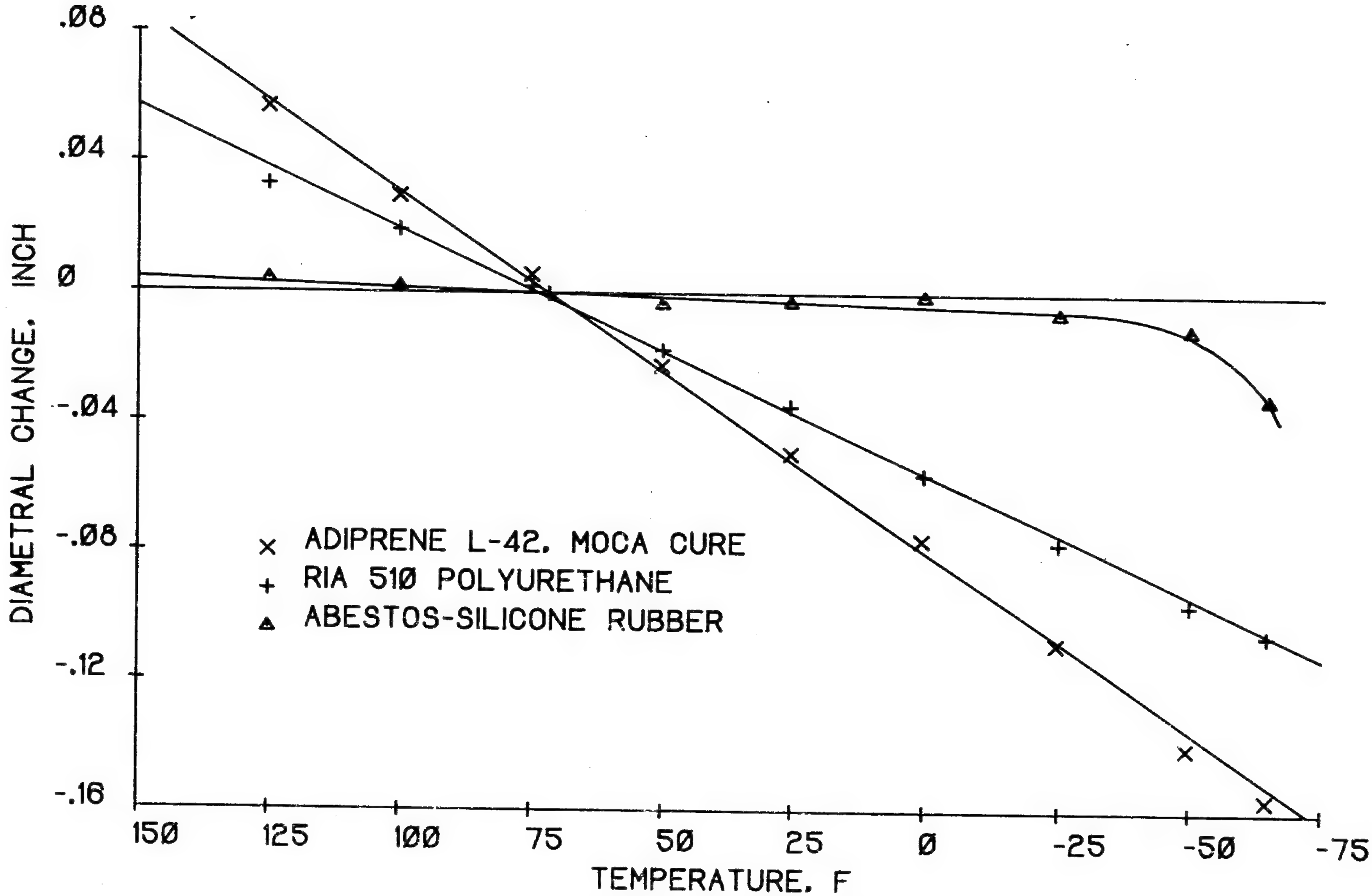

Fig. 7 Diametral changes as functions of temperature for the 175mm gun pads for which there is firing experience. Data taken for Ref. 1.

pads tested a number of years ago.[1] The data was taken from Ref. 1 but was generally corroborated by the present work. The excellent diametral stability of the asbestos-silicone rubber pad shown in this graph is because of its strongly anisotropic character owing to its wire mesh basket; silicone rubber itself has a coefficient of thermal expansion substantially greater than all the other elastomers tested. From Fig. 7 it can be concluded that a diametral change of -0.064 in. would be satisfactory because this is the change of the currently used RIA 510 polyurethane rubber pad at -10°F where it is safety certified. Furthermore, since the Adiprene L-42 pads were found to be satisfactory down to at least this same temperature, this value could be increased to -0.090 and probably to even -0.100 in.

The diametral change as a function of temperature for the 155mm howitzer pad made of the present RIA 510 polyurethane rubber is shown in Fig. 8. As above, from these data it can be concluded that satisfactory performance will be obtained with a diametral change of up to at least -0.063 in. as this is the change of the polyurethane pad at -40°F where it is safety certified.

A number of different formulations made with different prepolymers, different curing agents, additions of plasticizers, etc. were studied and the thermal dimensional stability data are shown in Figs. 9-12. The stabilities of all these pads were essentially the same; none of them were anywhere near good enough so that pads made from the

[1]Hynes, James T., Silicone-Asbestos Obturator Pads for 175mm Gun, M113A1, A Product Improvement, WVT-7101 (1971)

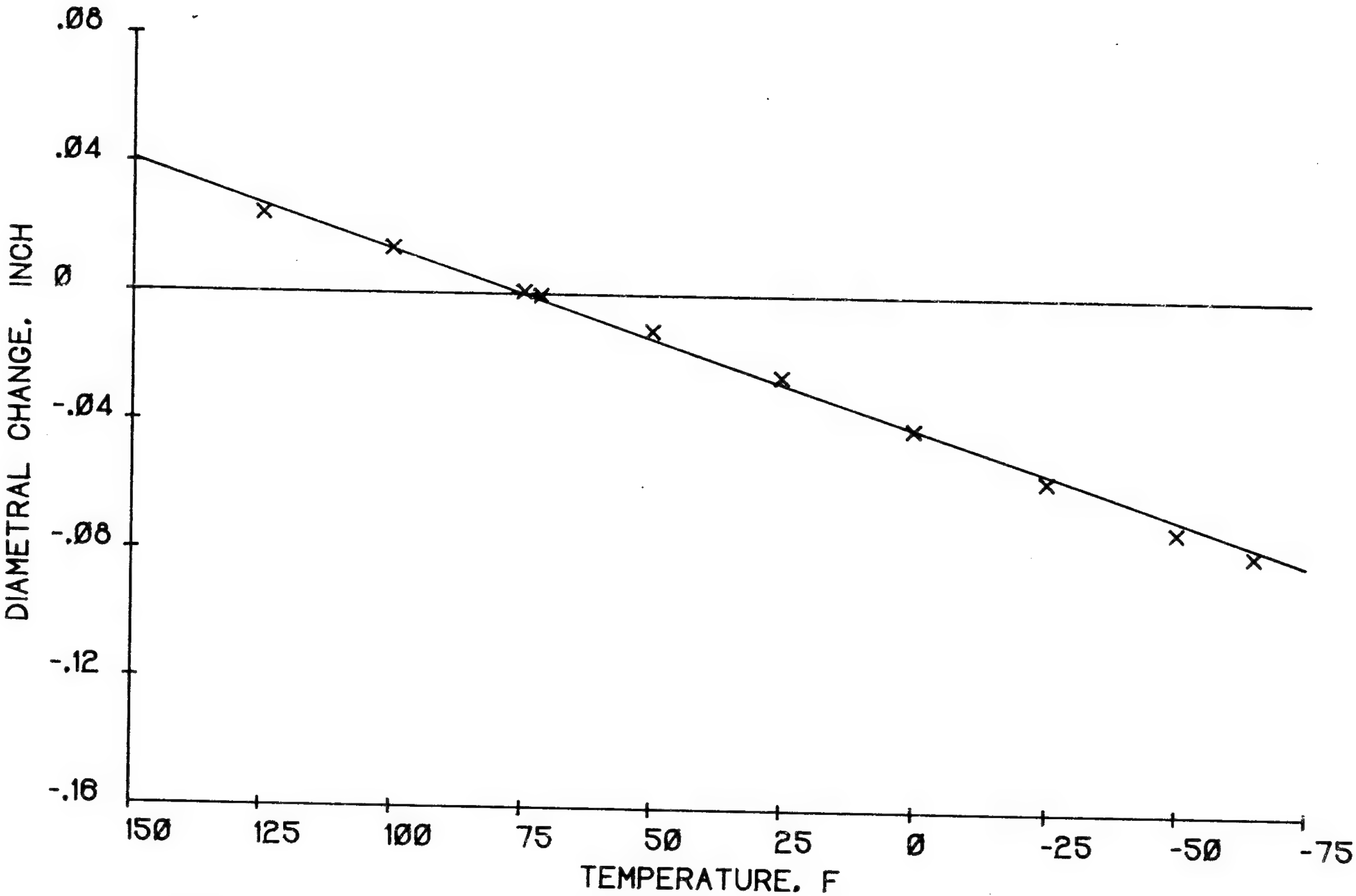

Fig. 8 Diametral change as a function of temperature for the 155mm howitzer pad made of the present RIA 510 polyurethane rubber.

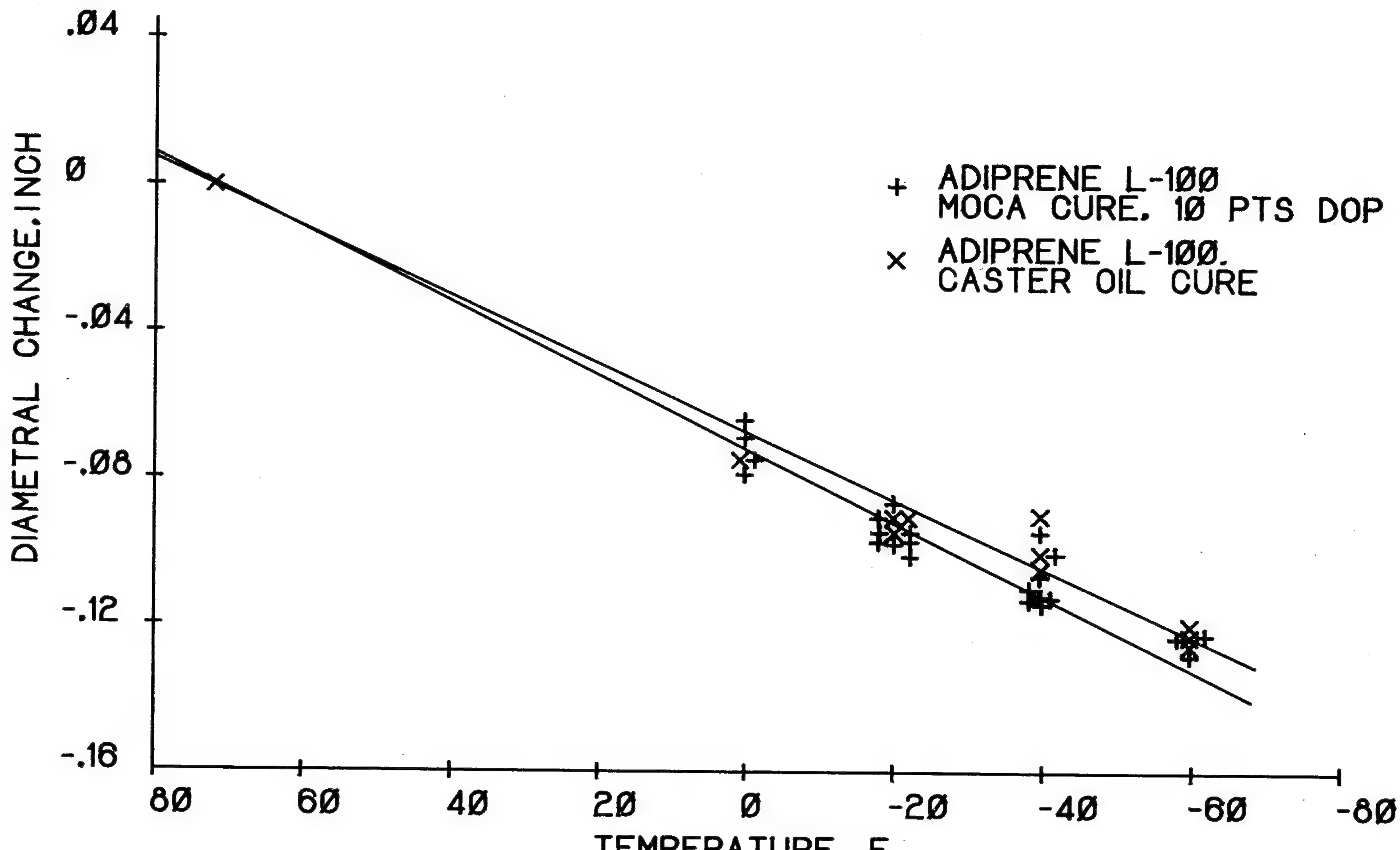

Fig. 9 Diametral change as a function of temperature for 165mm demolition gun pads made of experimental formulations.

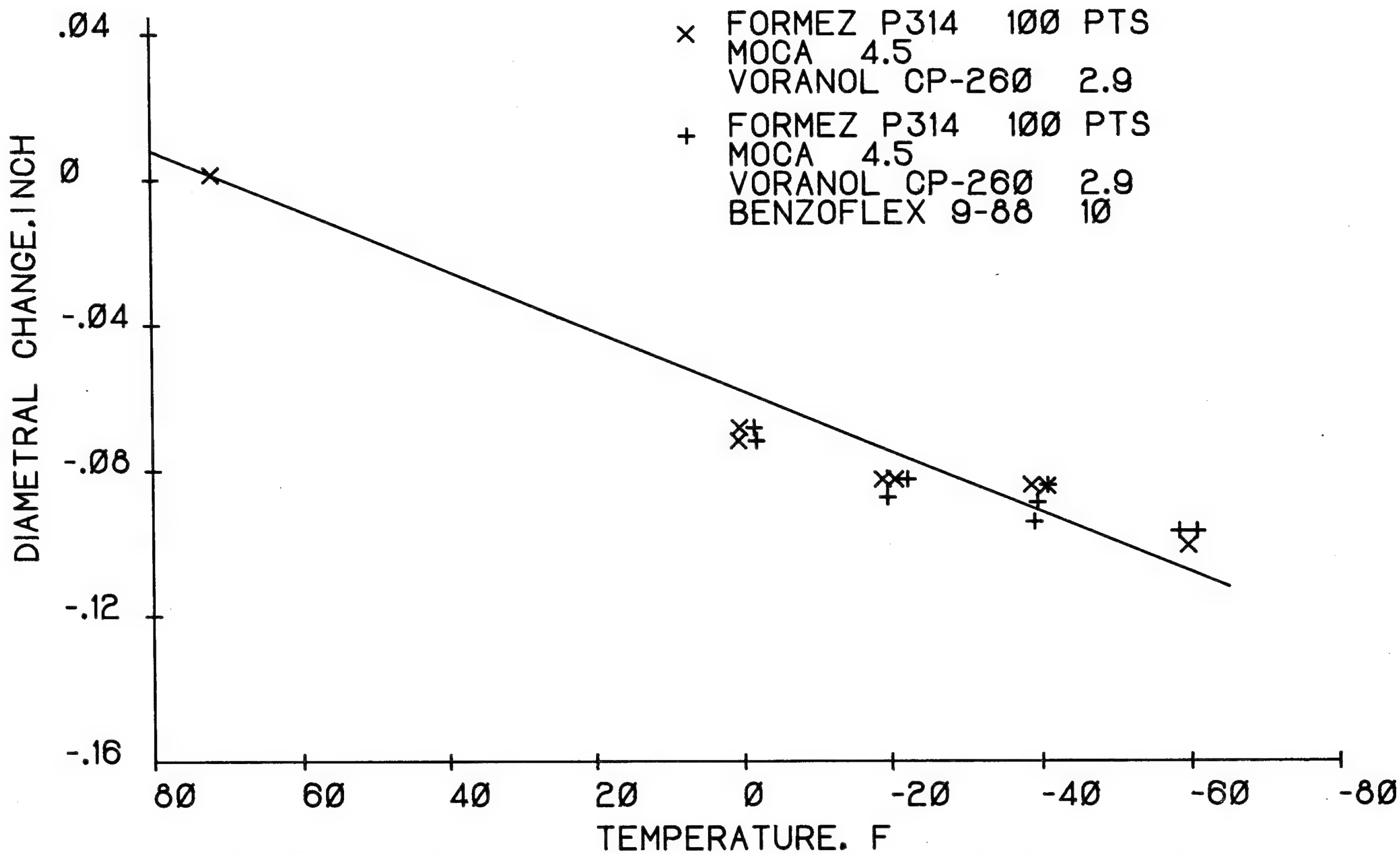

Fig. 10 Diametral change as a function of temperature for 165mm demolition gun pads made of experimental formulations.

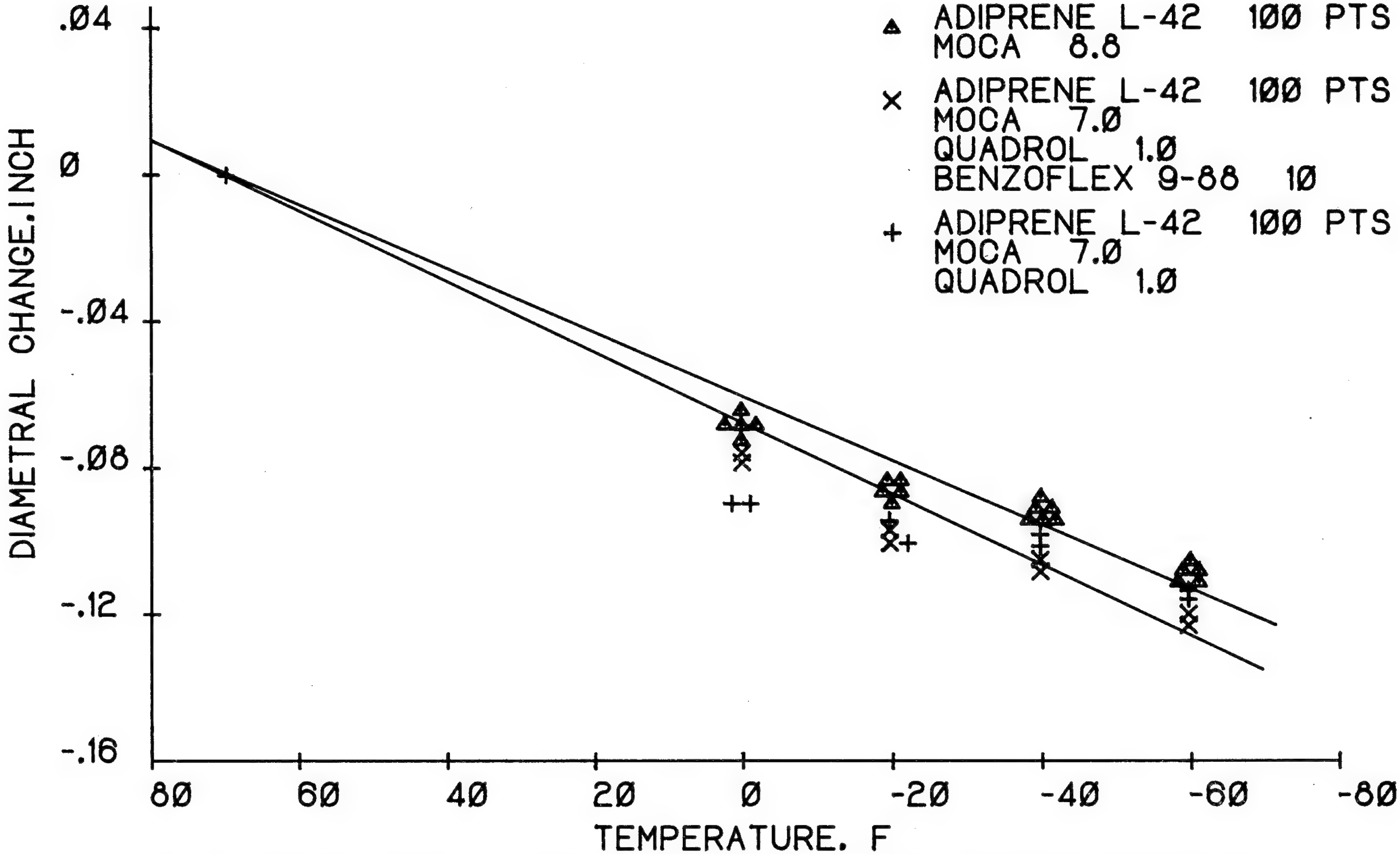

Fig. 11 Diametral change as a function of temperature for 165mm demolition gun pads made of experimental formulations.

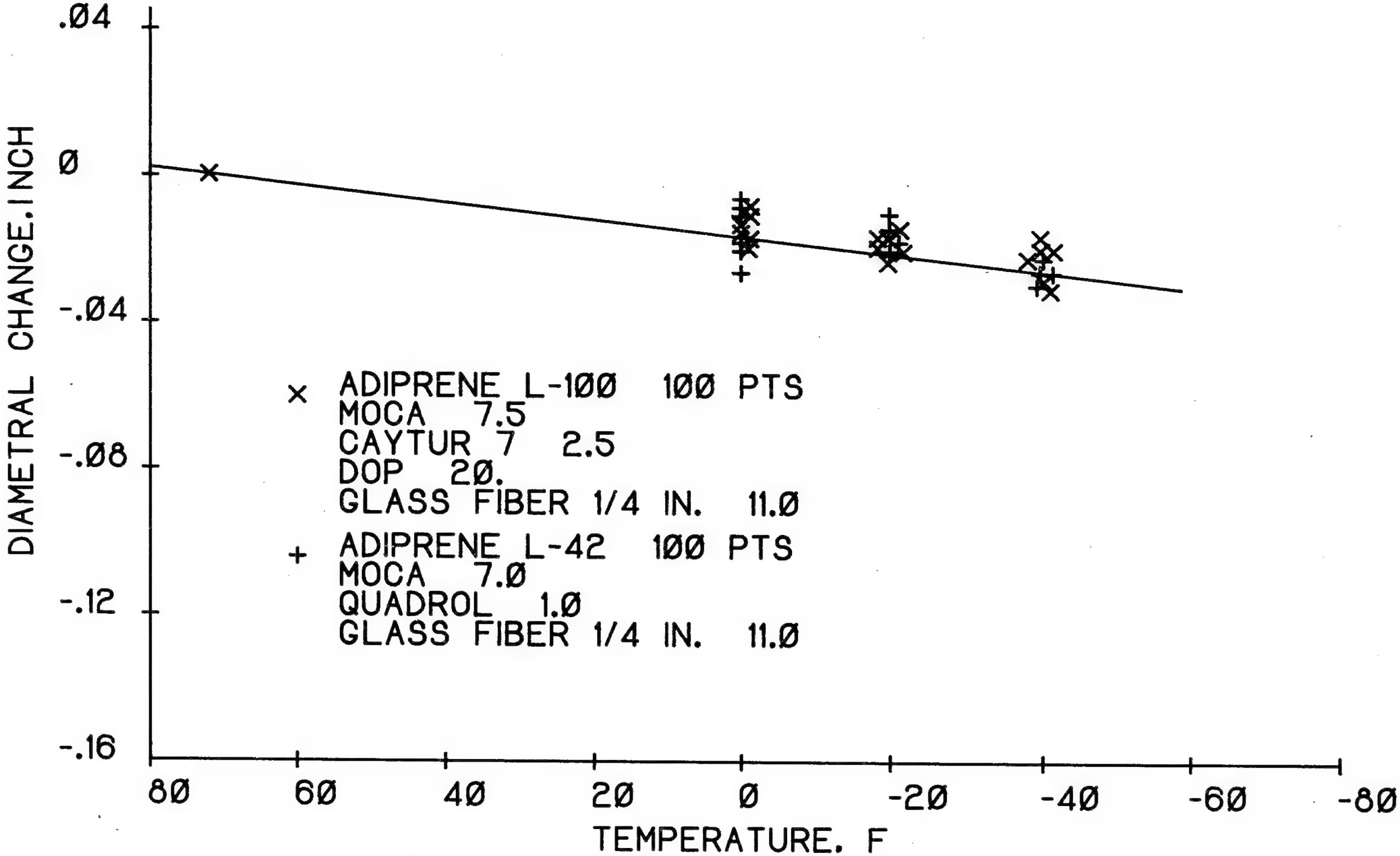

Fig. 12 Diametral change as a function of temperature for 165mm demolition gun pads made of two experimental formulations containing glass fibers.

formulations were likely to be satisfactory for the 175mm gun for the whole temperature range from 125° to -50°F. Therefore, it was concluded that only by making the pad anisotropic could the required dimensional stability be achieved. (This is not true for the 155mm howitzer pad.) Any oriented fibers in the obturator pad will produce anisotropic properties. They could be asbestos, cotton, nylon, glass, etc. but glass was chosen because these fibers are strong, inert, inexpensive, uniform, and the presence of impurities is not a problem. Furthermore, they bond well in an Adiprene formulation and they do not have a large amount of adsorbed water on their surfaces which degrades the mechanical properties of these castable polyurethane rubbers. Orientation of the glass fibers can be obtained by laminating glass cloth in the pad and this is very effective. As can be seen from Fig. 13, five laminations of glass cloth will decrease the diametral change of a 165mm demolition gun pad with temperature to only about 15% of its former value. However, almost as much improvement can be obtained in a much easier way. Since the uncured Adiprene mixture is poured into the mold with the mold in a horizontal position, if the glass fibers are reasonably long, they will automatically take up horizontal attitudes. This is an easy way to obtain fiber orientation and should also be a very inexpensive fabrication method. In Fig. 13 it can be seen that the addition of just 11.0 parts by weight of 1/4 in. fibers (based on 100 parts prepolymer) reduces the diametral change with temperature to about 22% of its former value. It is, however, necessary that the fibers be reasonably long. When this same proportion of 1/32 in. fibers

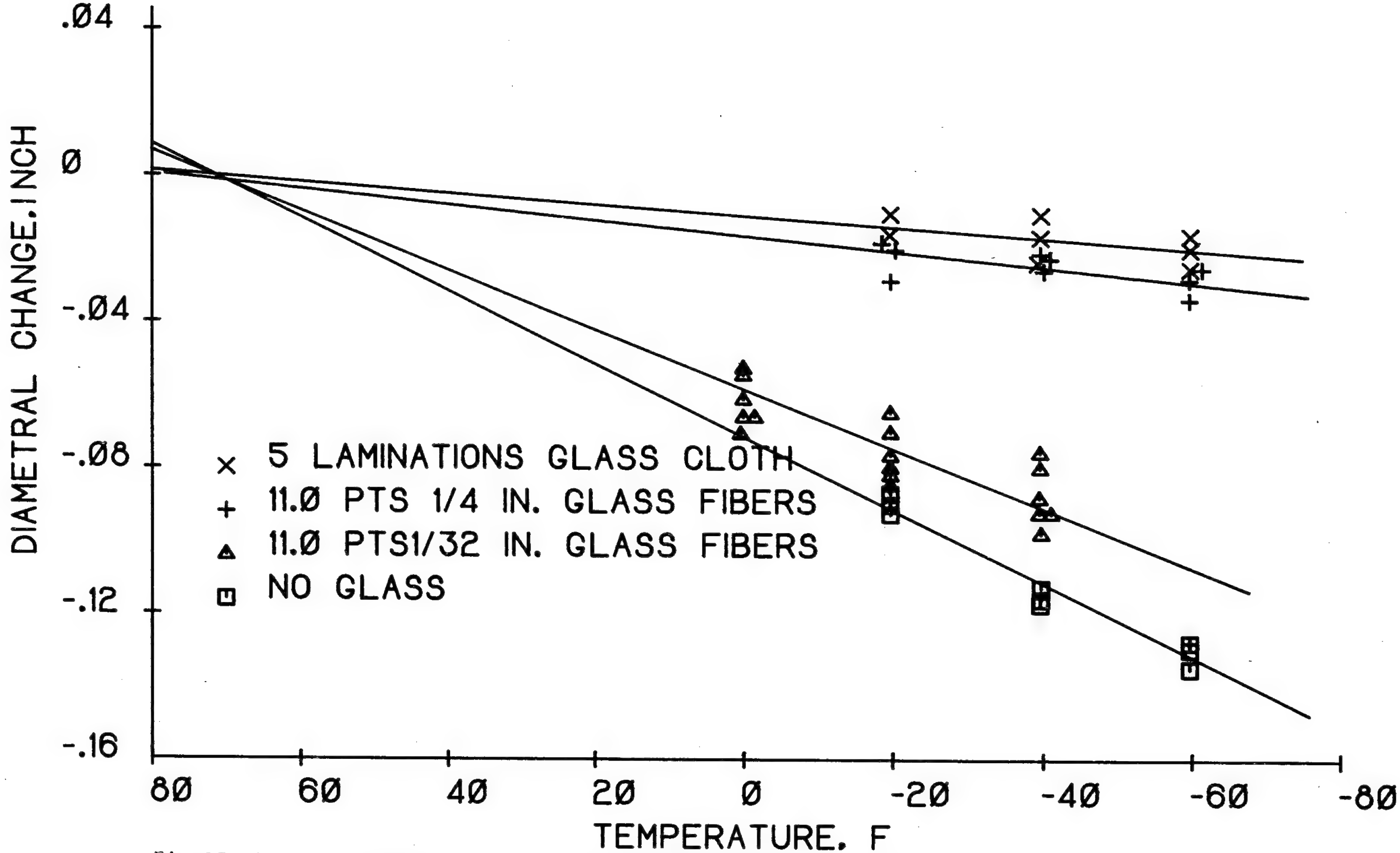

Fig 13 Diametral change as a function of temperature for 165mm demolition gun pads made of Adiprene L-100 polyurethane cured with MOCA showing the effect of addition of glass to the formulation.

fibers was used, the diametral change with temperature was 82% of its former value.

A greater proportion of glass fiber in the formulation will produce more anisotropy although the maximum amount which can be used is limited to about 15.5 parts of fiber to 100 parts of prepolymer because of increased handling difficulties. Fig. 14-16 show the diametral changes with temperature of a 165mm demolition gun pad with different proportions of fiber. These data were used to construct Fig. 17 which shows the diametral changes from ambient to a temperature of -50°F as a function of fiber content. This graph indicates that only about 1.6 parts of fiber would give the formulation the required dimensional stability to function to -50°F. More fiber, of course, would be required for operation at still lower temperatures and the dimensional stability of a particular formulation would vary from pad to pad.

Another factor to be taken into consideration is that the Adiprene rubber is viscoelastic to some extent. This means that the dimensions of the pads will continue to change as they remain at a temperature different from that at which they are stable. The dimensional stability conferred by the glass fibers is gained by restraining dimensional change in the radial direction. This restraint, of course, results in stresses, which in the case of a viscoelastic material, can slowly be relieved. The harder and more crosslinked a formulation, the less the dimensions of the pad will change. Two MOCA cured pads were allowed to stand at -35°F and their diameters measured periodically. (See Fig. 18). This relatively high temperature was chosen because the

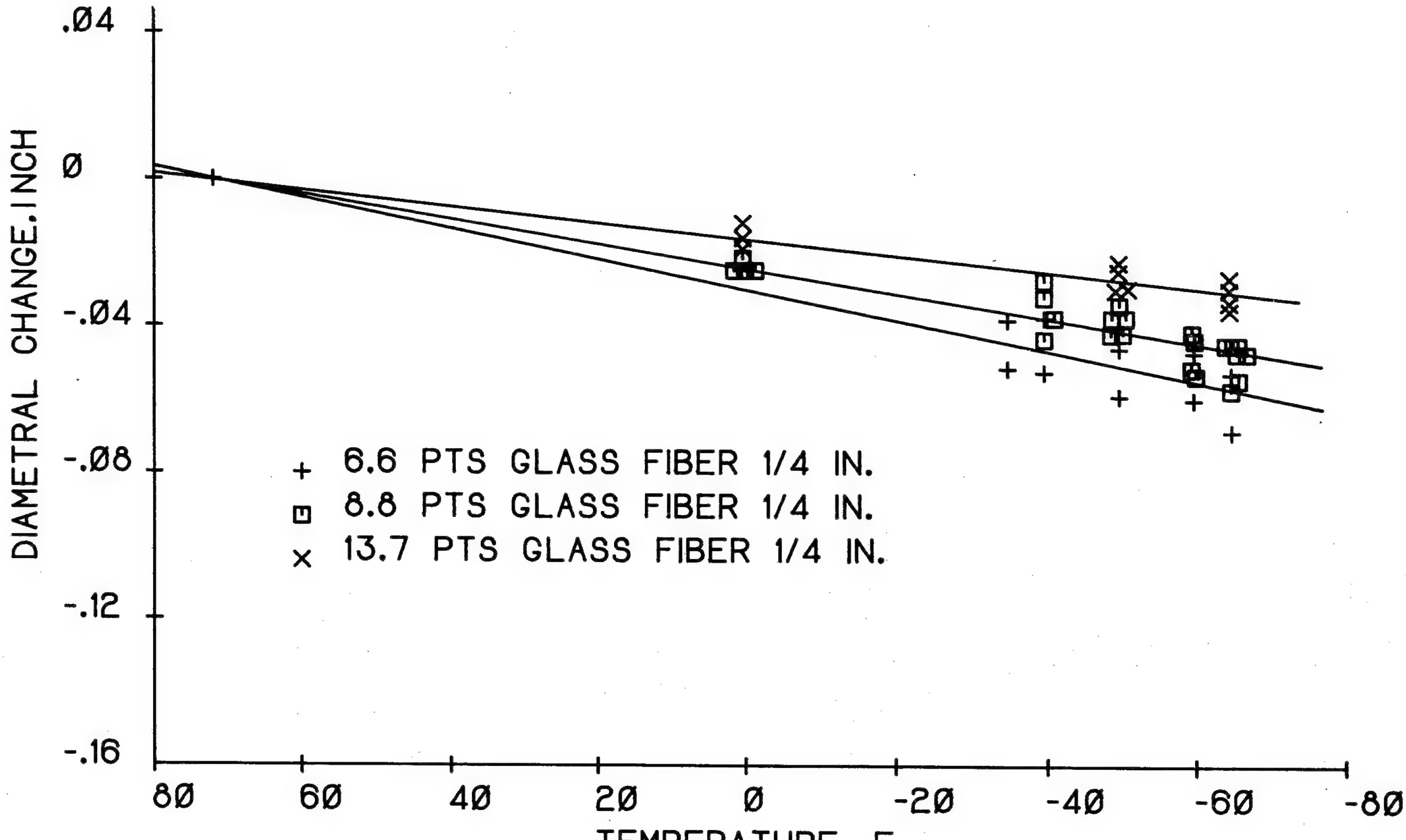

Fig. 14 Diametral change as a function of temperature for 165mm demolition gun pads made of Adiprene L-42 polyurethane cured with MOCA showing the effect of the proportion of 1/4 inch glass fiber in the formulation.

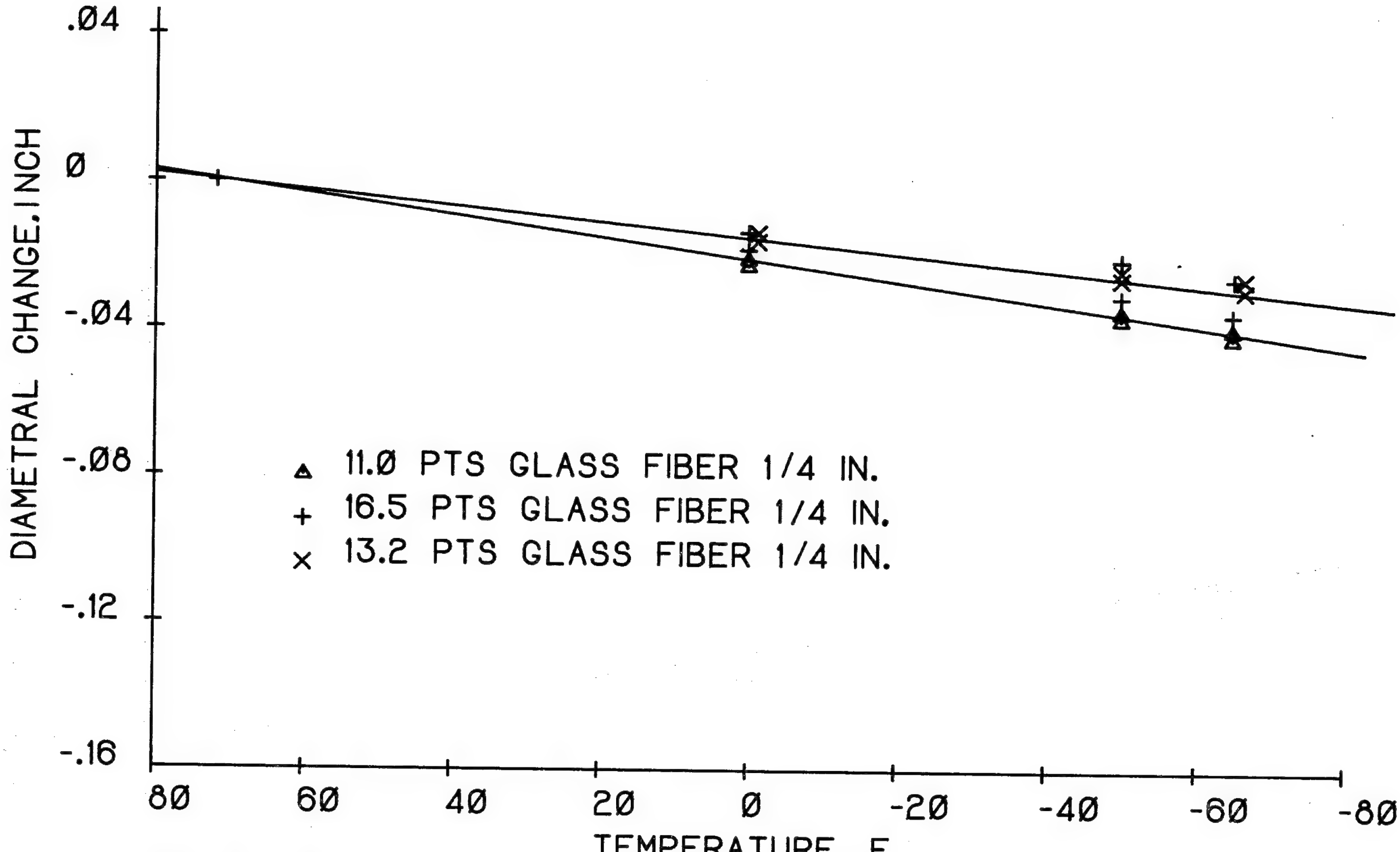

Fig. 15 Diametral change as a function of temperature for 165mm demolition gun pads made of Adiprene L-42 polyurethane cured with MOCA showing the effect of the proportion of 1/4 inch glass fiber in the formulation.

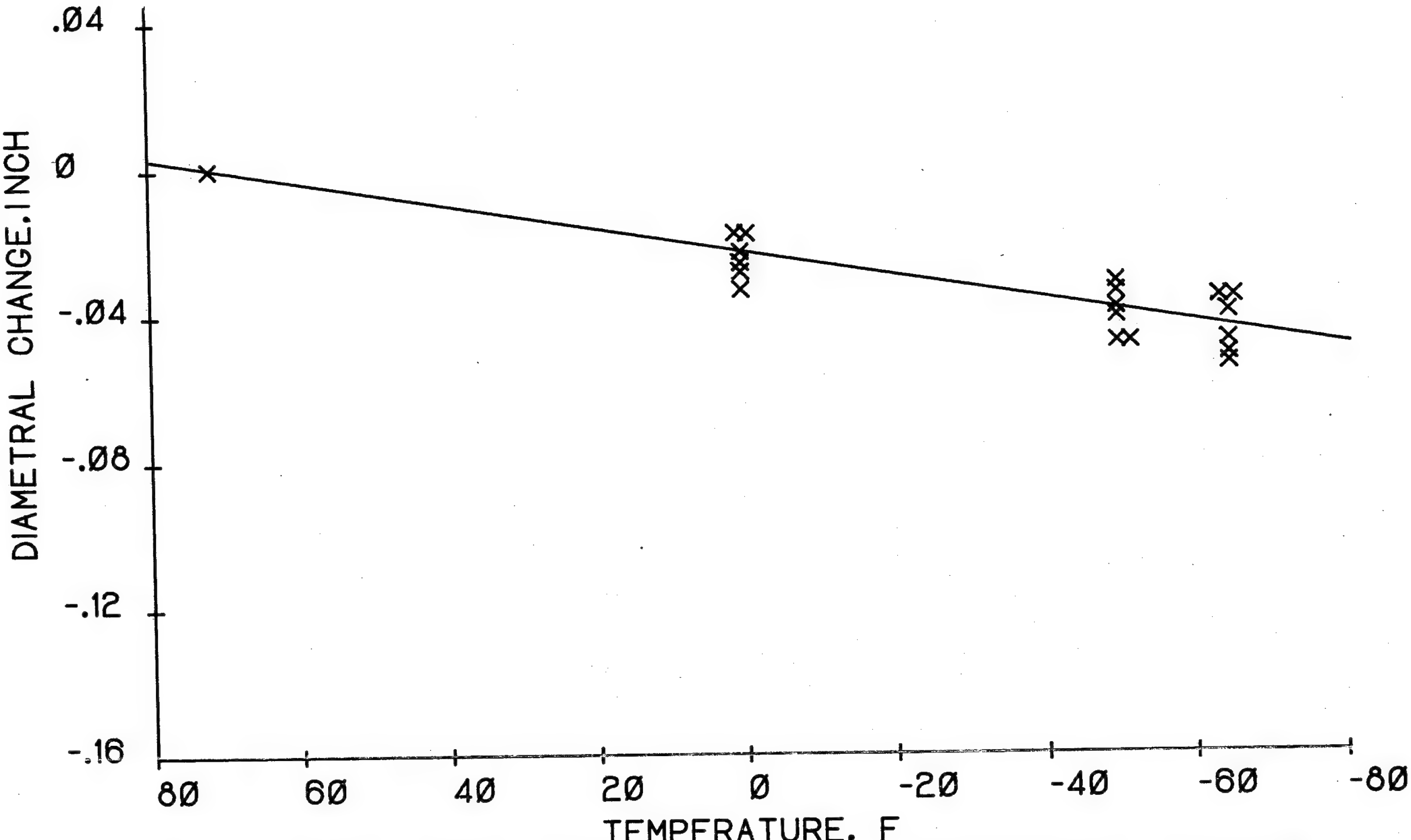

Fig. 16 Diametral change as a function of temperature for 165mm demolition gun pads made of Adiprene L-42 polyurethane cured with MOCA and containing 9.9 parts of 1/4 inch glass fiber.

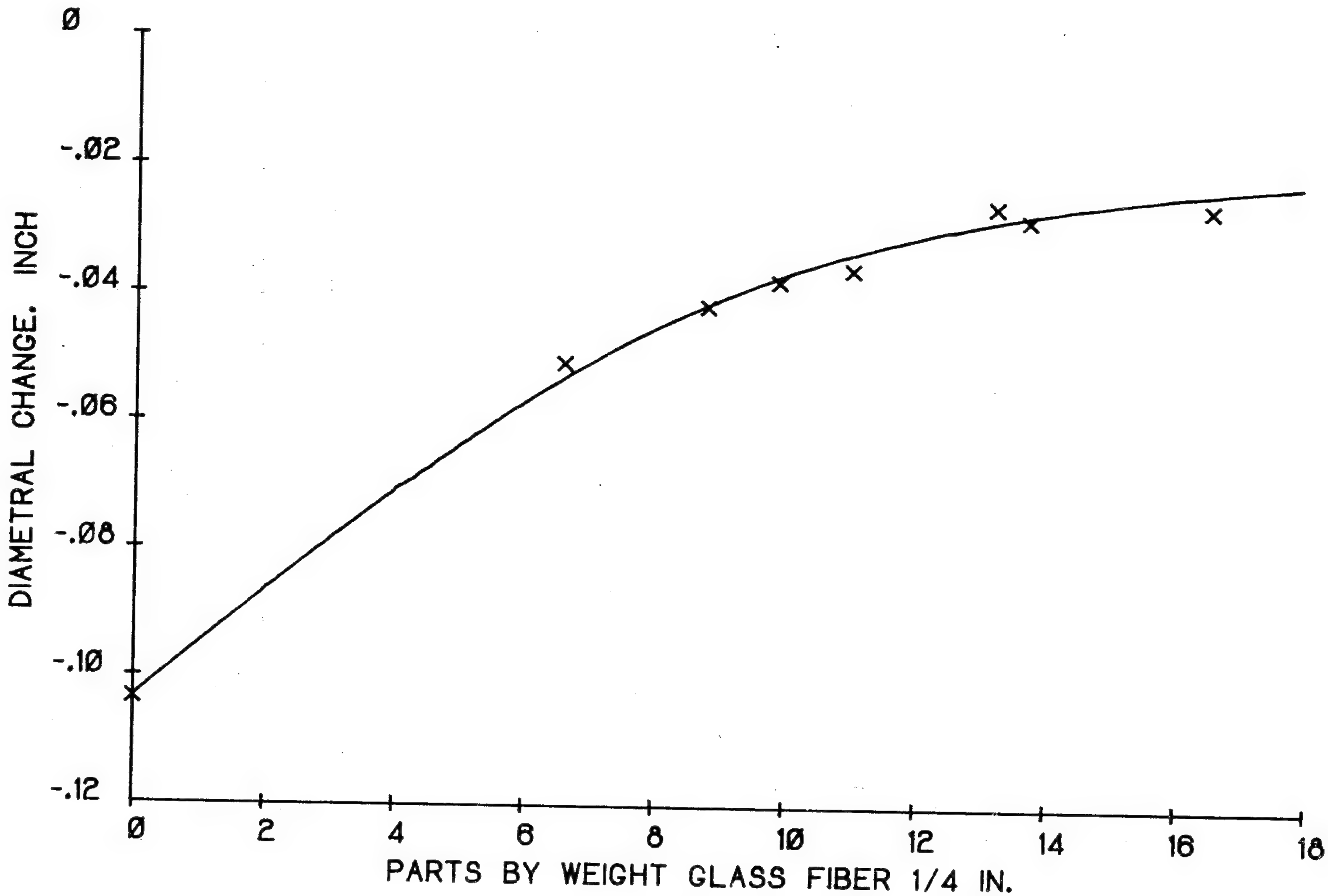

Fig. 17 Diametral change from ambient to -50^{o}F as a function of proportion of 1/4 inch glass fiber for 165mm demolition gun pads made of Adiprene L-42 cured with MOCA.

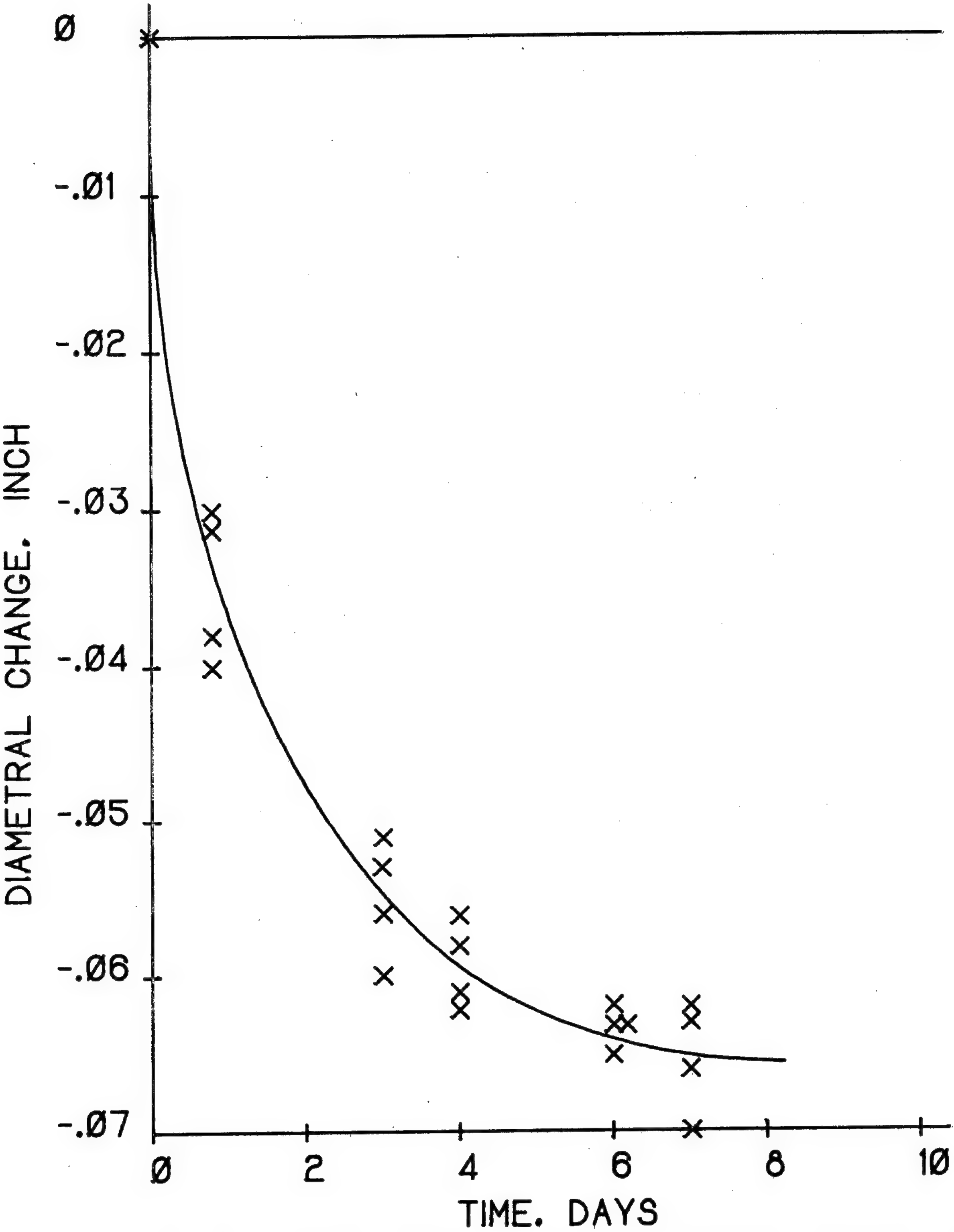

Fig. 18 Diametral change as a function of time at -35°F for 165mm demolition gun pads made of Adiprene L-42 cured with MOCA and containing 8.8 parts of 1/4 inch glass fiber based on 100 parts of resin.

pads will attain equilibrium more quickly. The lower the temperature, the greater the driving force but the higher the viscosity and the more resistance to dimensional change. In 24 hours, the length of time used for all the previous determinations, the change was only 0.037 in. but in two days it was 0.047 in. Equilibrium was attained in about 7 days. The change was about 175% of the 24 hour value so that more fiber would have to be used than predicted from the previous data if the pads are to be satisfactory after standing for a long time at the low temperature. It would thus be predicted that about 6.3 parts of fiber would be required for adequate stability down to -50°F if the pads are to stand at this temperature for a long time rather than the 1.6 parts obtained from Fig. 17. Actually, since a greater diametral change could probably be tolerated and continual standing at this very low temperature is unlikely, lower proportions of glass fiber than this would probably be satisfactory.

The next task was to fabricate a mold for the 175mm gun pad. The formulation shrinks when it cures and, since it is cured at a high temperature, the effective dimensions of the mold are greater than those measured at ambient temperature. The shrink on cure depends upon the proportion of glass fiber in the formulation, etc. and the task of dimensioning a mold for a glass fiber-containing formulation is made even more difficult because the shrink on cure is considerably different in the different directions. Consequently, the fabrication of a suitable mold which will produce the desired pad dimensions is a difficult matter and must be done in a number of steps with test pads molded after each

mold change. The mold was made by Garlock, Inc. of Palmyra, N.Y. because they have a great deal of experience with molds of this sort. As a guide for the initial mold dimensions, the differences between the mold dimensions and the pad dimensions for a number of MOCA cured formulations containing different proportions of fiber were measured. (See Figs. 19 and 20.) A satisfactory mold was fabricated although one of the important diametral dimensions was somewhat undersize. Further development work was done with 175mm gun pads made with this mold.

These 175mm gun pads were made by Garlock, Inc. in their developmental manufacturing facilities. They showed considerably more diametral change at low temperatures than did the 165mm demolition gun pads made at Watervliet Arsenal. The values for the pads for the two guns are compared in Fig. 21. Most of this can be attributed to the different dimensions of the pads. There were, of course, differences in fabrication methods but the fiber distribution was good and was about the same as that of the Watervliet Arsenal pads. It is difficult to see what other factor arising from the different fabrication methods could be responsible for this large difference in thermal dimensional stability. In any event, the fiber content for the formulation chosen for field testing was increased to 15.0 parts of fiber glass to 100 parts of prepolymer by weight. This large value was chosen because the information at this time was that a -65°F capability was desired. The diametral changes of these pads from ambient temperature to -65°F for a number of different formulations are shown in Table III.

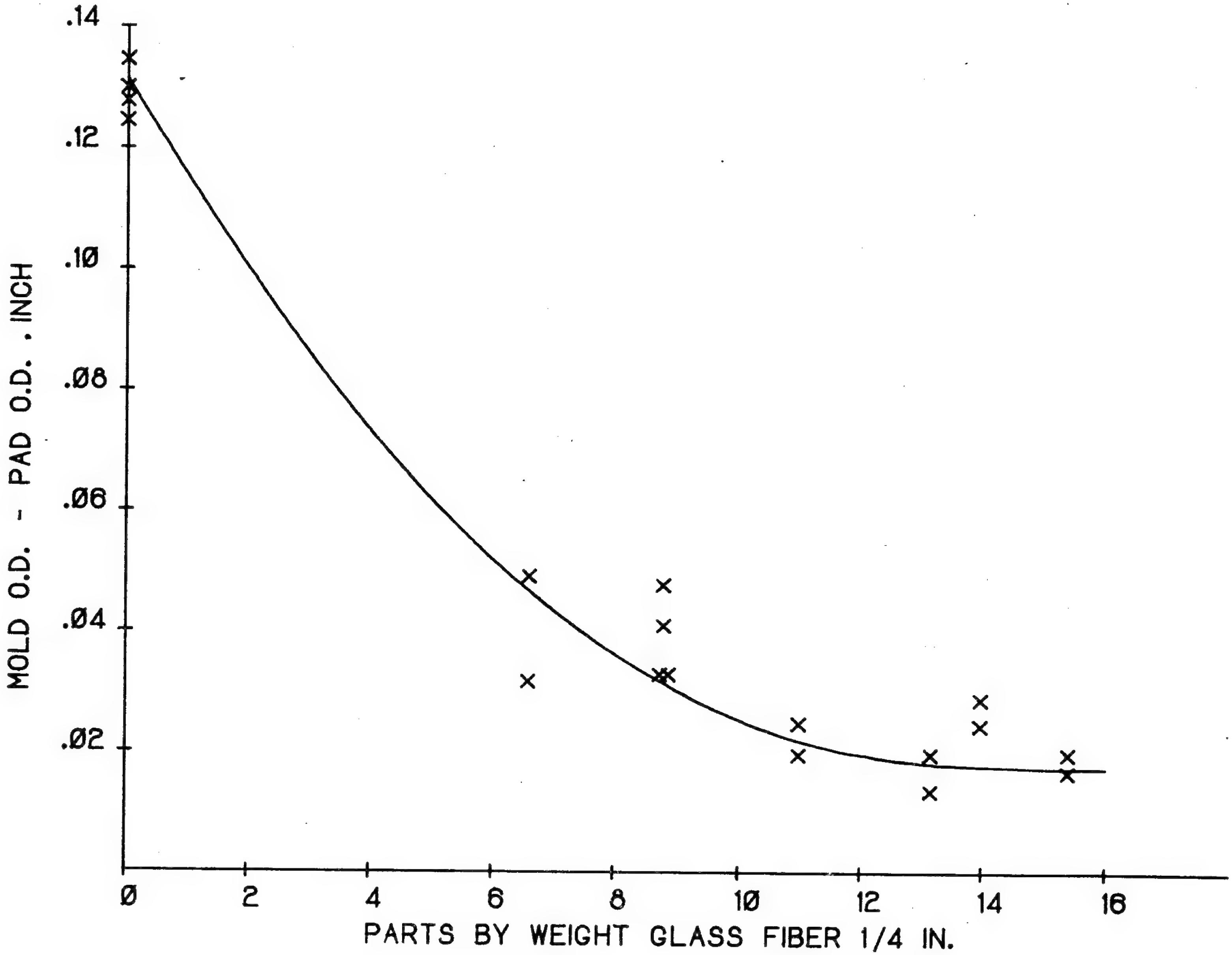

Fig. 19 Difference between mold outer diameter and pad outer diameter as a function of proportion of 1/4 inch glass fiber for 165mm demolition gun pads made of Adiprene L-42 cured with MOCA.

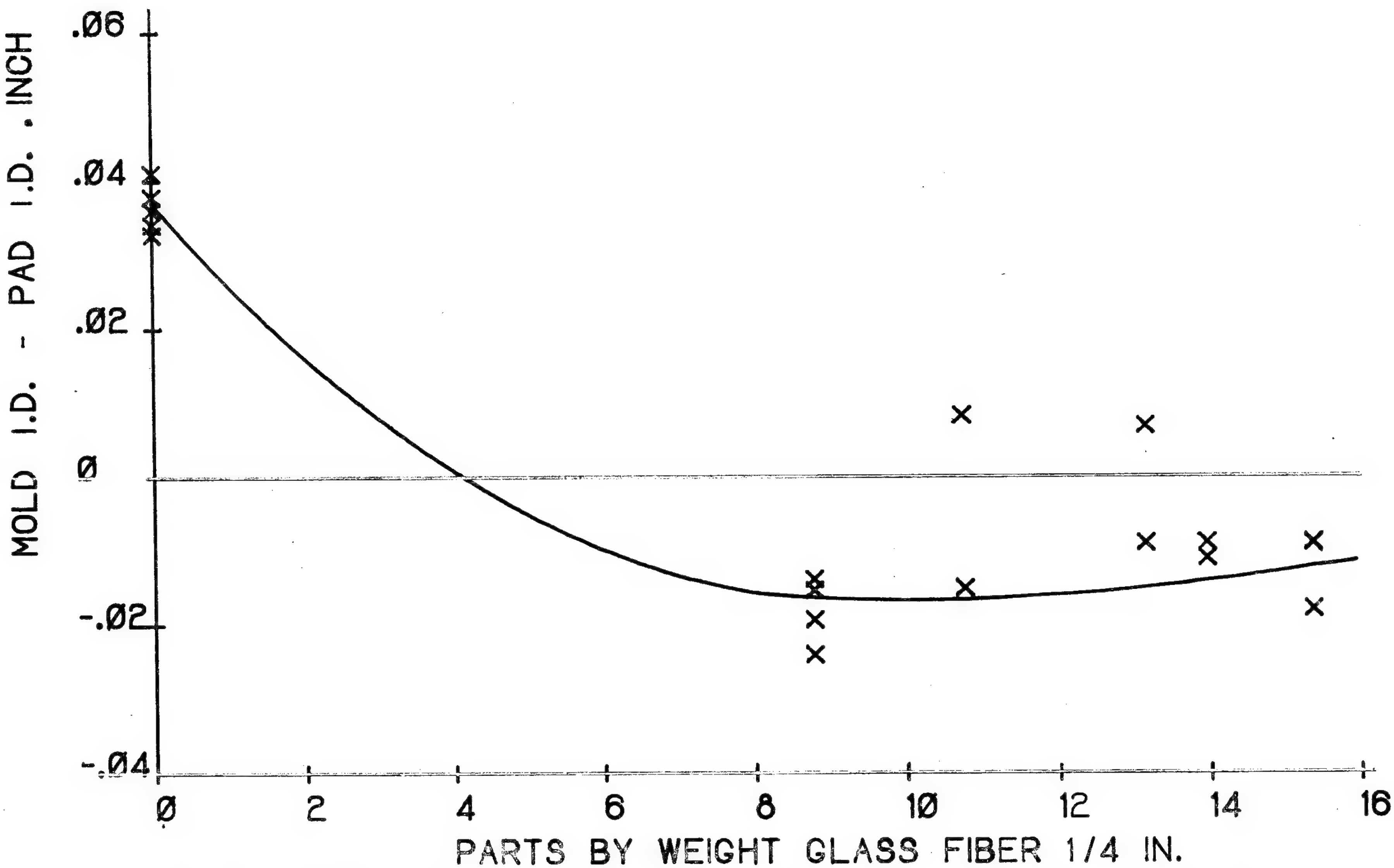

Fig. 20 Difference between mold inner diameter and pad inner diameter as a function of proportion of 1/4 inch glass fiber for 165mm demolition gun pads made of Adiprene L-42 cured with MOCA.

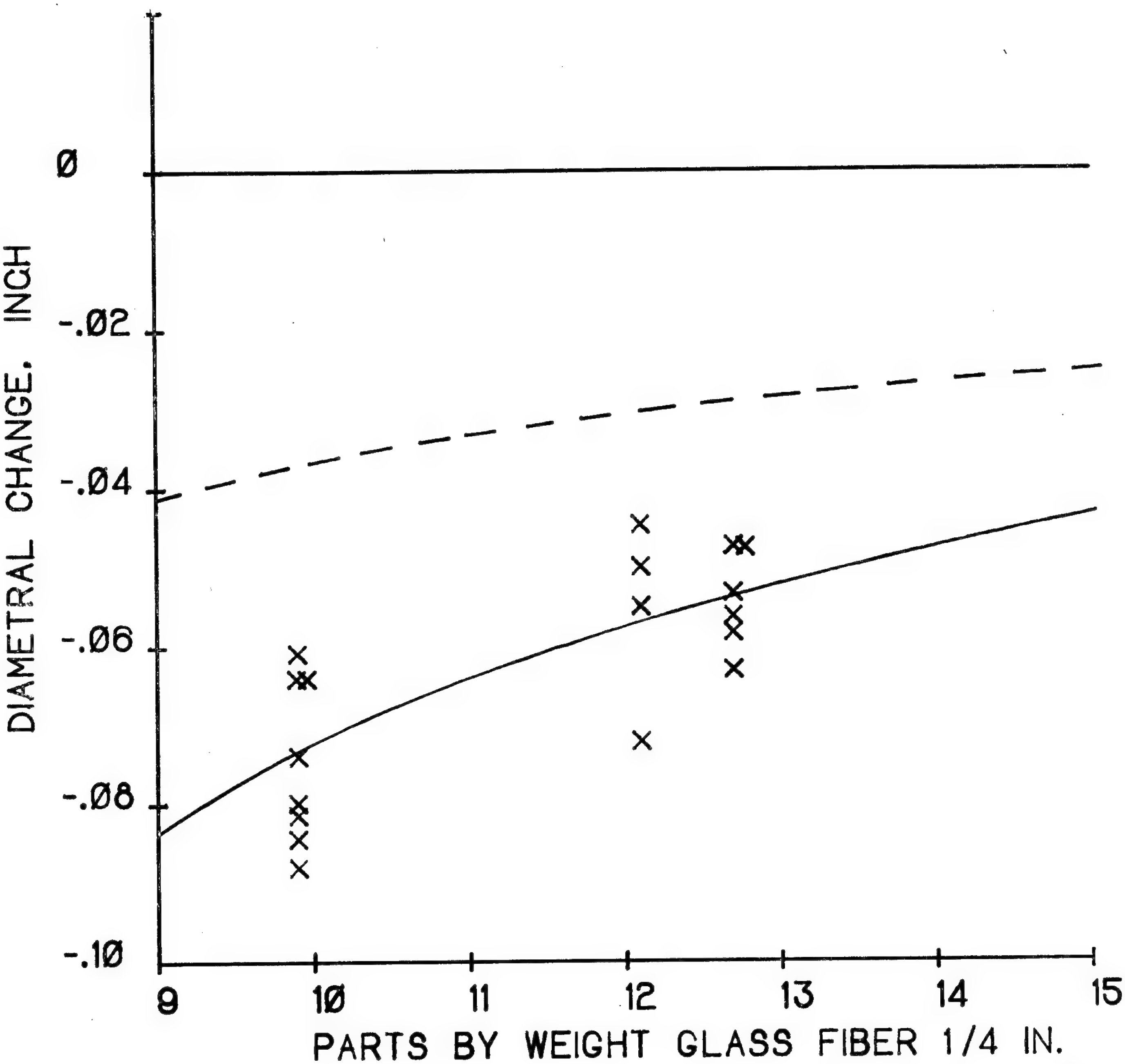

Fig. 21 Diametral change at -50°F as a function of proportion of 1/4 inch glass fiber for 175mm gun pads made of Adiprene L-42 cured with MOCA. These pads were made by Garlock, Inc. (The data at 12.7 parts were obtained by calculation from data taken at -65°F.) The dotted line is for the 165mm demolition gun pads made at Watervliet Arsenal.

Table III

Diametral Changes of 175mm Gun Pads from Ambient Temperature to -65 as a Function of Formulation and Proportion of Glass Fiber

Formulation	fiber glass content 12.7 pts	15.0 pts
Adiprene L-42, Caytur 21 cure	-0.044	
Garlock prepolymer, HQDBHEE cure	-0.043	
Adiprene L-42, MOCA cure	-0.060	
Adiprene L-42, HQDBHEE cure	-0.060	-0.052
Adiprene L-42, HQDBHEE-TMP cure	-0.062	

After the field development work with the 175mm gun pad, some additional field development work was done using the 155mm howitzer pad. The mold for this pad was also made by Garlock, Inc. The fabrication of this mold was a great deal easier because of the experience with the mold for the larger pad.

APPENDIX 5

Field Firing Experiments

175mm GUN M113A1

Actual firing tests were carried out at three different temperatures (four including ambient) in a climatic chamber at Aberdeen Proving Grounds. A total of five different pads representing three different formulations were tested although each was not tested at all temperatures. The climatic test temperatures were 125°, -25°, and -50°F and the results are shown in Table IV.

There were two rounds fired with a particular pad at one test temperature; the pads were first fired with Zone 3 rounds then with 115% upper pressure limit rounds. The test pads and gun were conditioned at the test temperature for at least 24 hours before firing and sufficient time was allowed between rounds to insure that the weapon and pad had returned to the test temperature. Before firing each pad, the seating of the seal rings were inspected. This was done by coating the tube seat with red lead and observing the transfer to the rings with normal opening and closing of the breech mechanism.

Ambient temperature

Two pads of different formulations were fired at ambient temperature. One was Adiprene L-42 cured with MOCA containing 12.7 parts of glass fiber (1/4 in.) and the other Adiprene L-42 cured with a HQDBHEE mixture (4.8% TMP) and containing 15.0 parts of glass fiber (1/4 in.). Both pads were fired without incident.

Table IV

Results of the Climatic Firing Tests with the 175mm Gun, M113A1

Formulation	Adiprene L-42, MOCA cure, 12.7 parts glass fiber (1/4 in.)		Adiprene L-42 HQDBHEE cure, 15.0 parts glass fiber (1/4 in.)	Adiprene L-42 HQDBHEE mixture cure (4.8% TMP) 15.0 parts glass fiber (1/4 in.)		
Amount undersize of rear sealing diam., inch	0.073	0.056	0.024	0.017	0.038	0.045
Ambient Temperature Zone 3 115% UPL	Sat. Sat.			Sat. Sat.		
125°F Zone 3 115% UPL	Sat. Sat. Small Amt. Extrusion			Sat. Sat. Small Amt. Extrusion		
-25°F Zone 3 115% UPL		Sat. UnSat. (Small leak)	Sat. Sat.			
-50°F Zone 3 115% UPL			Sat. Sat.		Sat. UnSat. 360° heavy blowby - heavy carbon 3 to 9 o'clock	Sat. UnSat. 360°heavy blowby and carbon-erosion damage

125°F temperature

The same pads tested above were fired at 125°F. Both sealed well. However, there was some extrusion at the corner where the seating surface for the front seal ring meets the circumferential surface of the pad. In neither case was there any serious damage to the pad. The MOCA cured pad showed a small amount of extrusion over a portion of its circumference. The HQDBHEE mixture cured pad apparently had extruded more because a small amount of the corner was missing over a portion of its circumference. This did not occur in tests at other temperatures and probably indicates that a harder, more durable formulation than that obtained with the HQDBHEE cure would be desirable for durability at high temperatures. In any case, the corner should be radiused rather than left sharp; this design change could obviate the problem at least with the harder MOCA cured pads. These two pads were then withdrawn from the test so that they could be measured to determine if there had been any dimensional change. (There had been none.)

-25°F temperature

The two pads which were added to the firing test were very similar to the two pads which were withdrawn. One was identical with the MOCA cured pad and the other pad was cured with only HQDBHEE rather than with the mixture containing 4.8% TMP. The HQDBHEE cured pad fired without incident. However, there was heavy carbon build-up on the rings at Zone 3 with the MOCA cured pad and this heavy carbon build-up was combined with some erosion on the rear ring at 115% UPL. There had been 360° contact of the rear seal ring on the seat with this pad but there had

been only 20-30% axial contact. There also had been two places where a knife blade could be inserted between the ring and the pad when the breech was open. While the diameters at the seating surface for the rear seal ring were too small with all the test pads because of a fault in the mold, it was smallest for the MOCA cured pads. The leakage of this pad was attributed to this dimensional fault rather than to poor sealing capability of the formulation. There was no indication from the shop tests that there was any problem. In any case, the MOCA cured pad was not tested at -50°F.

-50°F temperature

Three pads were tested at this temperature; one was the HQDBHEE cured pad tested at -25°F and two were pads cured with the HQDBHEE-TMP mixture. The HQDBHEE cured pad performed satisfactorily with both Zone 3 and 115% UPL rounds and the HQDBHEE-TMP cured pads performed satisfactorily with Zone 3 rounds. However, the HQDBHEE-TMP cured pads did not perform satisfactorily with the 115% UPL rounds. One of the pads had 360° blow-by and heavy carbon build-up over half of its circumference while the other had a 360° heavy carbon build-up and some blow-by. There was erosion on the rear portion of the tube seat in one location with the first pad. The fact that the diameter of the seating surface for the rear seal ring was too small (appreciably smaller than that of the HQDBHEE cured pad) and that shims were not used in the test doubtless contributed to the failure. However, shims were not used with the HQDBHEE cured pad either. (They should have been used because the pads were made to the standard dimensions and not made

oversize so that the shims could be eliminated.) All the shop tests indicate that the formulation cured with the TMP mixture is equal to that cured with only the HQDBHEE. However, it is possible that the speed of response of the pads cured with the TMP containing HQDBHEE might be lower. This formulation does develop more crosslinking in the structure which might slow its response.

In addition to these formal firing tests, some of the pads made with the MOCA cured formulation were informally tested at ambient temperature at Aberdeen Proving Ground. They performed satisfactorily and their durability at this temperature appeared good. However, a large number of rounds were not fired so firm conclusions about their durability cannot be drawn.

155mm HOWITZER M185

Actual firing tests were carried out with the M185 howitzer also in a climatic chamber at Aberdeen Proving Grounds. Three pads made from the formulation where the Adiprene L-42 was cured with the HQDBHEE-TMP mixture were fired with two Zone 8 rounds at 125°, -30°, and -50°F. As above, the test pads and the gun were conditioned at the test temperature at least 24 hours before firing and sufficient time was allowed between rounds to insure that the weapon and pad had returned to the test temperature. At both 125° and -30°F there was a 100% seal between the seal rings and the tube seat at the test temperatures as determined with red lead in the usual manner before firing. At -50°F there was 360° contact of the rear ring with the seat for all rounds but the axial contact varied from 90 to 100% except for one round with

one pad where it was only 75%. However, there was good obturation with every round and the pads performed very satisfactorily. The dimensions of the pads for this cannon were much closer to the specified dimensions than were those made for the 175mm gun.

Pads of the same formulation were also used for some ambient temperature firing at Aberdeen Proving Grounds. Their obturation was satisfactory but not enough rounds were fired for their durability to be evaluated. The split of the front seal ring cut the corresponding location on the pads appreciably more than was the case with the 175mm gun pads even after fewer rounds. This cannon is intrinsically harder on its obturator pads than is the 175mm gun.

155mm HOWITZER XM199

A number of pads of the formulation where the Adiprene L-42 was cured with the HQDBHEE mixture (containing 4.8% TMP) were fired at Zone 8 in this cannon at ambient temperature at Jefferson Proving Grounds. After anywhere between 3 and 59 rounds the breech became difficult or impossible to close. There was, however, no significant change in the pad dimensions during the firing. The difficult closing of the breech was caused, not by an increase in the size of the pad, but by pieces of the pad lodging between the mushroom head and the front sealing ring at the location of the split. This kept the ring from contracting when the breech was closed. The front seal ring becomes deformed after only a relatively few Zone 8 rounds and when it becomes sufficiently deformed, it is held in an expanded condition. The XM199 operates at a higher pressure than does the M185 and is more damaging

to the obturator pad and front seal ring. The combination of the relatively soft HQDBHEE cured Adiprene and the thermally inert glass fiber is unsuited for this cannon unless the front seal ring is redesigned. This is because the elastomer is too readily cut and the fibers in the formulation are not degraded by the high temperatures and lodge at the expansion joint. This keeps the ring expanded and prevents the breech from closing.

For this cannon, and perhaps the M185 as well, a different, harder and more durable formulation is required. Therefore, a pad was made of Adiprene L-42 cured with duPont's 158 Curative. This curing agent is a diamine similar in many respects to MOCA but without proven health hazards. It produces a hard and durable elastomer. The pad was used for 57 Zone 8 rounds in the XM199 howitzer at Jefferson Proving Grounds with very little damage to the pad and no problems in closing the breech of the cannon. In this test the front seal ring had been modified in that the split was made slightly longer which reduced cutting of obturator pads of all compositions. However, this formulation appeared considerably more durable than was the HQDBHEE cured formulation. Whether it possesses sufficient thermal dimensional stability without the glass fiber for operation at -50°F is doubtful but it appears to be hard and tough enough so that fibers could not be plucked from it during firing.